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Report on the performance test of the Model 405 nm NOx monitor manufactured by 2B Technologies for measuring NO, NO_2 and NO_x

TÜV report: 936/21242468/A
Cologne, February 19th, 2019

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Report on the performance test of the Model 405 nm NOx monitor manufactured by 2B Technologies for measuring NO, NO2 and NOx

AMS designation: Model 405 nm

Manufacturer: 2B Technologies
2100 Central Avenue
Boulder, Colorado 80301
USA

Test period: April 2018 to February 2018

Date of report: February 19th, 2019

Report Number: 936/21242468/A

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Scope of the report:

Report:	180	pages
Manual	183	
Manual	53	pages
Total	236	pages

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1. Summary and certification proposal

1.1 Summary Overview

2B Technologies commissioned TÜV Rheinland Energy GmbH to carry out performance testing for the Model 405 nm air quality monitoring system measuring the components NO, NO_2 and NO_x. The test was performed in respect of the following standards and requirements:

- VDI Guideline 4202 part 1: Performance test, declaration of suitability, and certification of point-related measuring systems for gaseous air pollutants of April 2018
- EN 14211: Ambient air – Standard method for the measurement of the concentration of nitrogen dioxide and nitrogen monoxide by chemiluminescence, of August 2012
- Guide to the Demonstration of Equivalence of Ambient Air Monitoring Methods of January 2010

The Model 405 nm ambient air monitor uses UV absorption to measure NO, NO_2 and NO_x directly. Thus, the measuring principle does not correspond to the to chemiluminscence as the EU reference method. Appendix 1 presents the field test results of comparison measurements with the reference method for NO_x (chemiluminescence). Measurement results were evaluated in accordance with the Guide to the Demonstration of Equivalence of Ambient Air Monitoring Methods.

In contrast with a CLD analyser, the instruments measuring principle determines NO_2 and NO directly. The output for the NO_x value is always a calculated result. This is why NO and NO_2 were considered separately for every test item reported here. NO was tested in accordance with the requirements of EN 14211. For the purpose of testing NO_2 (tested measuring range 0–500 µg/m³ (0–261 nmol/mol)), test gas target values were adapted to the NO_2 measuring range. This, too, is specified in standard EN 14211. An additional cross-sensitivity test was performed for NO_2.

The tests were performed in a TÜV Rheinland Energy GmbH laboratory and in a three-months field test in Cologne. The measured ranges are indicated below:

Table 1: Measuring ranges tested

Measured components:	measuring range in [µg/m³] [1]	Measuring range in [ppb] or [nmol/mol]
NO	0–1 200	0–962
NO_2	0–500	0–261

[1] The specifications refer to 20 °C and 101.3 kPa

During performance testing, the AMS met the requirements specified in standard EN 14211 (2012) and VDI 4202, part 1 (2018).

TÜV Rheinland Energy GmbH therefore recommend the instrument's approval as a performance-tested measuring system for continuous monitoring of air quality affected by nitrogen oxides.

1.2 Certification proposal

Based on the positive results obtained, the following recommendation on the announcement of the AMS as a certified system is put forward:

AMS designation:

Model 405 nm for NO, NO_2 and NO_x

Manufacturer:

2B Technologies, Boulder, USA

Field of application:

For the continuous measurement of nitrogen oxide concentrations from stationary sources in ambient air

Measurement ranges during performance testing:

Component	Certification range	Unit
Nitrogen monoxide	0–1 200	µg/m³
Nitrogen dioxide	0–500	µg/m³

Software version:

Version 36B

Restrictions

None

Note:

1. This report on the performance test is available online at www.qal1.de.
2. As the measuring system does not provide password protection, it has to be mounted in a lockable cabinet.
3. Equivalence with the reference method in accordance with the requirements of the Guide to the Demonstration of Equivalence of Ambient Air Monitoring Methods was demonstrated.

Test Report:

TÜV Rheinland Energy GmbH, Cologne
Report no.: 936/21242468/A dated February 19th, 2019

1.3 Summary report on test results

Performance criterion	**Requirement**	**Test result**	**Satisfied**	**Page**
7 Performance criteria				
7.3 General requirements				
7.3.1 Measured value display	The measuring system shall have an operative measured value display as part of the instrument.	The measuring system has an operative measured value display at the instrument front.	yes	36
7.3.2 Calibration inlet	The measuring system may have a test gas inlet separate from the sample gas inlet.	The measuring system does not have a test gas inlet separate from the sample gas inlet. Test gas enters the measuring system via the sample gas inlet.	not applicable	37
7.3.3 Easy maintenance	Maintenance should be possible without larger effort, if possible from outside.	Maintenance takes reasonable effort and is possible with standard tools from the outside.	yes	38
7.3.4 Functional check	Particular instruments required to this effect shall be considered as part of the measuring system and be applied in the corresponding sub-tests and included in the assessment.	The tested measuring system does not have internal devices for operating the functional check.	not applicable	39
7.3.5 Set-up times and warm-up times	The instruction manual shall include specifications in this regard.	Set-up times and warm-up times have been determined.	yes	40
7.3.6 Instrument design	The instruction manual shall include specifications in this regard.	Specifications made in the instruction manual concerning instrument design are complete and correct.	yes	41
7.3.7 Unintended adjustment	It shall be possible to secure the adjustment of the measuring system against illicit or unintended adjustment during operation. Alternatively, the user manual shall specifically note that the measuring system may only be installed in a secured area.	The measuring system is not secured against unintended and unauthorised adjustment of instrument parameters by way of a password. The NO/NO2/NOx monitor has to be installed inside a lockable measuring rack or container to protect it from unintended or unauthorised adjustment of instrument parameters. This is also indicated on page 6 of the operation manual.	yes	42
7.3.8 Data output	The output signals shall be provided digitally and/or as analogue signals.	Measured signals are output as analogue signals (0–2.5 V) and digital signals (via Modbus, RS 232).	yes	43
7.3.9 Digital interface	The digital interface shall allow the transmission of output signals, status signals, and others. Access to the measuring system shall be secured against unauthorised access.	Digital transmission of measured values operates correctly.	yes	44

Performance criterion	**Requirement**	**Test result**	**Satisfied**	**Page**
7.3.10 Data transmission protocol	Shall meet the requirements stipulated in Table 1 of VDI Guideline 4202 part 1.	By default, the measuring system comes with an installed Modbus protocol. Measured and status signals are transmitted correctly.	yes	45
7.3.11 Measuring range	The upper limit of measurement shall be greater or equal to the upper limit of the certification range.	By default, the measuring range is set to 0–500 µg/m³ for NO2 and 0–1200 µg/m³ for NO. Supplementary measuring ranges up to 0–2 and 10 ppm are possible. The measuring system's upper limit of measurement exceeds the upper limit of the certification range in each case.	yes	46
7.3.12 Negative output signals	May not be suppressed (life zero).	The measuring system also provides negative output signals.	yes	47
7.3.13 Failure in the mains voltage	Uncontrolled emission of operation and calibration gas shall be avoided; instrument parameters shall be secured by buffering against loss; when mains voltage returns, the instrument shall automatically reach the operation mode and start the measurement.	On return of mains voltage, the instrument returns to normal operating mode after a warm-up phase and automatically resumes measuring.	yes	48
7.3.14 Operating states	The measuring system shall allow their control by telemetrically transmitted status signals.	The measuring system provides various ports to ensure comprehensive monitoring and control via an external computer.	yes	49
7.3.15 Switch-over	Switch-over between measurement and functional check and/or calibration shall be possible telemetrically.	In principle, it is possible to perform all necessary activities in the context of functional testing on the instrument itself or remotely with the help of an external PC connected to the internet.	yes	50
7.3.16 Instrument software	Shall be displayed when switched on. Changes affecting instrument functions shall be communicated to the test laboratory.	The instrument's software version is displayed. Software changes are communicated to the test laboratory.	yes	51

Performance criterion	**Requirement**	**Test result**	**Satisfied**	**Page**
7.4 Requirements on performance characteristics for testing in the laboratory				
7.4.1 General requirements	The manufacturer's specifications in the instruction manual shall not contradict the results of the performance test.	Tests were performed using the performance characteristics specified in VDI standard 4202, part 1 (2018) and standard EN 14211 (2012)	yes	52
7.4.2 Test requirements	Has to comply with the requirements set out in VDI standard 4202-1:2018.	Tests were performed using the performance characteristics specified in VDI standard 4202, part 1 (2018) and standard EN 14211 (2012)	yes	53
Section 8.4 provides a summary of the evaluation of performance characteristics determined in the laboratory.				
7.5 Requirements on performance characteristics for testing in the field				
7.5.1 General requirements	Has to comply with the requirements set out in VDI standard 4202-1:2018.	Tests were performed using the performance characteristics specified in VDI standard 4202, part 1 (2018) and standard EN 14211 (2012)	yes	77
7.5.2 Location for the field test	The monitoring station for the field test is to be chosen according to the requirements of 39. BImSchV such that the expected concentrations of the measured components to be measured correspond to the designated task. The equipment of the monitoring station shall allow the implementation of the field test and shall fulfil all requirements considered to be necessary during measurement planning.	The field test location was selected in compliance with the 39th BImSchV.	yes	78
7.5.3 Test requirements	The measuring systems shall be installed in the monitoring station and, after connecting to the existing or separate sampling system, activated properly. The adjustments of the measuring system shall meet the specifications of the manufacturer. All adjustments are to be documented in the test report.	During the field test, the measuring system was operated and serviced according to the manufacturer's instructions.	yes	79
Section 8.5 provides a summary of the evaluation of performance characteristics determined in the laboratory.				

Performance criterion	Requirement	Test result	Satis-fied	Page
8.4 Procedures for determination of the performance characteristics in laboratory according to EN 14211				
8.4.3 Response time	Rise and fall response time ≤ 180 s each. Difference between rise and fall response time ≤ 10 s.	The values determined remained considerably below the maximum permissible response time of 180 s at all times. The maximum response time determined for instrument 1 was 28 s for NO and 36 s for NO2. For instrument 2 it was determined at 28 s for NO and 37.5 s for NO2.	yes	87
8.4.4 Short-term drift	The short-term drift at zero must be ≤ 2.0 nmol/mol/12 h. The short-term drift at span level must be ≤ 6.0 nmol/mol/12 h.	For NO, the value for the short-term drift at zero point was -0.53 nmol/mol for instrument 1; for instrument 2, it was -0.51 nmol/mol. For NO, the value for the short-term drift at span point was -1.69 nmol/mol for instrument 1; for instrument 2, it was -0.20 nmol/mol. For NO2, the value for the short-term drift at zero point was 0.17 nmol/mol for instrument 1; for instrument 2, it was 0.65 nmol/mol. For NO2, the value for the short-term drift at span point was -2.08 nmol/mol for instrument 1; for instrument 2, it was 0.98 nmol/mol.	yes	92
8.4.5 Repeatability standard deviation	The performance criteria are as follows: Repeatability standard deviation at zero shall not exceed 1.0 nmol/mol. At a sample gas concentration at the reference point it shall not exceed 3.0 nmol/mol.	For NO, the value for the repeatability standard deviation at zero point was 0.67 nmol/mol for instrument 1; for instrument 2 it was 0.50 nmol/mol. Repeatability standard deviation at reference point was 1.07 nmol/mol for instrument 1 and 1.03 nmol/mol for instrument 2. For NO2, the value for the repeatability standard deviation at zero point was 0.35 nmol/mol for instrument 1; for instrument 2 it was 0.57 nmol/mol. Repeatability standard deviation at reference point was 0.88 nmol/mol for instrument 1 and 0.78 nmol/mol for instrument 2.	yes	98
8.4.6 Lack of fit of linearity of the calibration function	The deviation from the linearity of the calibration function at zero shall not exceed 5.0 nmol/mol. At concentrations above zero, it shall not exceed 4% of the measured value.	Component NO The deviation from the linear regression line for instrument 1 is -0.06 nmol/mol at zero point and no more than 0.66% of the target value for concentrations above zero. The deviation from the linear regression line for instrument 2 is -0.70 nmol/mol at zero point and no more than 1.15% of the target value for concentrations above zero. Component NO2 The deviation from the linear regres-	yes	102

			sion line for instrument 1 is 1.50 nmol/mol at zero point and no more than 2.36% of the target value for concentrations above zero. The deviation from the linear regression line for instrument 2 is -0.24 nmol/mol at zero point and no more than 3.29% of the target value for concentrations above zero.		
8.4.7	Sensitivity coefficient to sample gas pressure	The sensitivity coefficient to sample gas pressure shall be ≤ 8.0 nmol/mol/kPa.	For NO, the sensitivity coefficient to sample gas pressure was 0.34 nmol/mol/kPa for instrument 1; for instrument 2 it was 0.43 nmol/mol/kPa. For NO2, the sensitivity coefficient to sample gas pressure was 0.19 nmol/mol/kPa for instrument 1; for instrument 2 it was 0.17 nmol/mol/kPa.	yes	109

Performance criterion	Requirement	Test result	Satisfied	Page
8.4.8 Sensitivity coefficient to sample gas temperature	The sensitivity coefficient to sample gas temperature shall be ≤ 3.0 µmol/mol/K.	For instrument 1, the sensitivity coefficient to sample gas temperature was 0.08 nmol/mol/K for NO; for NO2, it was 0.10 nmol/mol/K. For instrument 2, the sensitivity coefficient to sample gas temperature was 0.05 nmol/mol/K for NO; for NO2, it was 0.10 nmol/mol/K.	yes	112
8.4.9 Sensitivity coefficient to surrounding temperature	The sensitivity coefficient to surrounding temperature temperature shall be ≤ 3.0 µmol/mol/K.	The sensitivity coefficient to the surrounding temperature bst did not exceed the performance criterion specified at 3.0 nmol/mol/K. For the purpose of uncertainty calculation, the largest value bst is used for both instruments. For NO, this would be 0.250 nmol/mol/K for instrument 1 and 0.253 nmol/mol/K for instrument 2. For NO2, this would be 0.197 nmol/mol/K for instrument 1 and 0.206 nmol/mol/K for instrument 2.	yes	115
8.4.10 Sensitivity coefficient to electrical voltage	The sensitivity coefficient to electrical voltage shall not exceed 0.30 nmol/mol/V.	At no test item did the sensitivity coefficient to electrical voltage bv exceed the value of 0.3 nmol/mol/V specified in standard EN 14211. For the purpose of uncertainty calculation, the largest bv is used for both instruments. For NO, this is 0.01 nmol/mol/V for instrument 1 and 0.00 nmol/mol/V for instrument 2. For NO2, this is 0.00 nmol/mol/V for instrument 1 and 0.02 nmol/mol/V for instrument 2.	yes	119
8.4.11 Interferents	Interferents at zero and at concentration c_t for NO (500 ± 50 nmol/mol). Deviations for interferents H_2O, CO_2 and NH_3 shall not exceed 5.0 nmol/mol.	At zero point the result for the interference were 1.87 nmol/mol (AMS 1) and 0.33 nmol/mol (AMS 2) for H2O, 1.27 nmol/mol (AMS 1) and 1.03 nmol/mol (AMS 2) for CO2 and finally 1.37 nmol/mol (AMS 1) and 1.67 nmol/mol (AMS 2) for NH3. At zero point the result for the interference were 0.07 nmol/mol (AMS 1) and 0.23 nmol/mol (AMS 2) for H2O, -0.07 nmol/mol (AMS 1) and 0.07 nmol/mol (AMS 2) for CO2 and finally 0.97 nmol/mol (AMS 1) and 0.93 nmol/mol (AMS 2) for NH3. The following results were obtained for the cross-sensitivity at the limit value ct: NO: 2.37 nmol/mol for instrument 1 and 2.80 nmol/mol for instrument 2; H2O: -0.07 nmol/mol for instrument 1 and -0.33 nmol/mol for instrument 2; CO2 and 2.13 nmol/mol for instrument	yes	123

		1 and 0.97 nmol/mol at NH3. The following results were obtained for the cross-sensitivity at the limit value ct: NO2: 2.27 nmol/mol for instrument 1 and 2.13 nmol/mol for instrument 2; H2O: -0.57 nmol/mol for instrument 1 and 0.37 nmol/mol for instrument 2; CO2 and 0.83 nmol/mol for instrument 1 and 0.80 nmol/mol at NH3.		
8.4.12 Averaging test	The averaging effect shall not exceed 7% of the measured value.	The performance criterion specified by standard EN 14211 is fully satisfied.	yes	127

Performance criterion	Requirement	Test result	Satisfied	Page
8.4.13 Difference sample/calibration port	The difference between the sample and calibration ports shall not exceed 1%.	This test criterion does not apply. The measuring system is not equipped with a test gas inlet separate from the sample gas inlet. Test gases have to be fed via the sample inlet.	not applicable	131
8.4.14 Converter efficiency	The converter efficiency shall be at least 98%.	At a converter efficiency of 99.6%, the performance criterion specified by EN 14211 is fully satisfied.	yes	132
8.4.15 Residence time in the analyser	The residence time in the analyser shall not exceed 3.0 s.	Residence time in the analyser was 1.2 s.	yes	132
8.5 Determination of the performance characteristics during the field test according to EN 14211				
8.5.4 Long-term drift	The long-term drift at zero point shall not exceed ≤ 5.0 nmol/mol. Long-term drift at span level shall not exceed 5% of the certification range.	Maximum long-term drift at zero point $D_{l,z}$ for NO was at 0.39 nmol/mol for instrument 1 and 0.94 nmol/mol for instrument 2. Maximum long-term drift at reference point $D_{l,s}$ for NO was at 1.29% for instrument 1 and 0.89% for instrument 2. Maximum long-term drift at zero point $D_{l,z}$ for NO2 was at -0.61 nmol/mol for instrument 1 and 0.53 nmol/mol for instrument 2. Maximum long-term drift at reference point $D_{l,s}$ for NO2 was at 0.61% for instrument 1 and 1.33% for instrument 2.	yes	136
8.5.6 Inspection interval	The period of unattended operation of the AMS shall be at least 2 weeks.	The necessary maintenance tasks determine the period of unattended operation. In essence, these include contamination checks, plausibility checks and checks of potential status/error warnings. The external particle filter needs replacing at the measurement site after having been subjected to dust loading. EN 14211 requires checking of zero and span points at least once every two weeks.	yes	145
8.5.5 Reproducibility standard deviation for NO2 under field conditions	Reproducibility standard deviation under field conditions shall not exceed 5% of the mean value over a period of three months.	The reproducibility standard deviation for NO2 under field conditions was 3.41% as a percentage of the mean value over the three-months field test period. Thus, the requirements of EN 14211 are satisfied.	yes	141
8.5.7 Period of availability of the analyser	Availability of the analyser shall be at least 90%.	The availability is 100%. Thus, the requirement of EN 14211 is satisfied.	yes	146

2. Task Definition

2.1 Nature of the test

2B Technologies commissioned TÜV Rheinland Energy GmbH to carry out performance testing for the Model 405 nm ambient air monitor. The test was carried out as a complete performance test.

2.2 Objectives

The AMS is designed to determine nitrogen oxide concentrations in ambient air in the following concentration ranges:

Component	Certification range	Unit
Nitrogen monoxide	0 - 1200	µg/m³
Nitrogen dioxide	0 - 500	µg/m³

The Model 405 nm ambient air monitor uses UV absorption to measure NO, NO_2 and NO_x directly.

The task was to carry out performance testing in line with the applicable standards and taking into consideration the latest developments in the field.
The test was performed on the basis of the following standards:

- VDI standard 4202 part 1: Automated measuring systems for air quality monitoring – Performance test, declaration of suitability, and certification of point-related measuring systems for gaseous air pollutants, April 2018
- EN 14211: Ambient air – Standard method for the measurement of the concentration of nitrogen dioxide and nitrogen monoxide by chemiluminescence, of August 2012
- Guide to the Demonstration of Equivalence of Ambient Air Monitoring Methods of January 2010

3. Description of the AMS tested

3.1 Measuring principle

The Model 405 nm ambient air monitor is a continuous nitrogen oxide analyser. The instrument uses direct UV absorption as a measuring principle. It was designed for the continuous measurement of NO, NO_2 and NO_x in ambient air.

Figure 1: View of the Model 405 nm analyser

The model 405 NO_2/NO/NOx monitor is designed to measure atmospheric nitrogen dioxide (NO_2), nitrogen oxide (NO) and NOx (NO + NO_2) in a dynamic range from just a few ppb up to 10 ppm for NO_2 and 2 ppm for NO based on the detection of visible light at a wave length of 405 nanometres (nm).

The model 405 inside the analyser uses the absolute method to measure NO_2 on the basis of Lambert Beer's law. NO_2 measurement relies on a conventional absorption method. NO_2 is analysed at a UV light wave length of 405 nm. The necessary measurement path length of 2 m is realised by using a measurement cell with a tube design which facilitates low volumes and fast gas replacement.

Nitrogen oxide is measured by measuring UV light intensities with and without adding ozone for oxidising NO to NO_2. As described in more detail below, the result is a "semi-direct" measurement of NO in that the NO concentration is output directly and not based on subtraction of NO_2 concentration from a total NO_x concentration. Instead, the NOx concentration is computed as the sum of the measurements of NO_2 and NO.

The pump sucks in sample air through the instrument at a constant flow rate of 1.5 l/min. The NO_2 scrubber valve alternately bypasses and sends the sample air through a heated NO_2 scrubber to remove all NO_2 in the sample. The NO_2-scrubbed or unscrubbed air passes through the reactor volume and the DewLine^{TM} Nafion Tubes (to equilibrate humidity), through the optical cell and through the cell flow meter. Alternate switching of the NO_2 scrubber valve once every 5 seconds allows the measurement of a light intensity in the absence (I_o) of NO_2 and presence (I) of NO_2. The Beer-Lambert Law is then used to calculate the concentration of NO_2 from I and I_o:

$$[NO_2] = \frac{1}{L\sigma} ln\left(\frac{I_o}{I}\right)$$

Here, L is the path length (~2.1 m) and the absorption cross section (~6.06×10^{-19} cm^2 $molec^{-1}$) for NO_2 is constant. The measurement provides an absolute NO_2 concentration in $molecules/cm^3$. From the temperature and pressure we use the ideal gas law to calculate an NO_2 into ppb in the cell.

Nitrogen dioxide in units of ppb is then given by:

$$[NO_2]_{ppb} = 10^9 \frac{[NO_2]}{[Air]} = 10^9 \frac{RT}{N_{A.}PL\sigma} ln\left(\frac{I_o}{I}\right)$$

where N_A is Avogadro’s number ($6.02214129 \times 10^{23}$ molec/mol), R is the gas constant (82.05746 cm^3 atm $^{K-1}$ mol^{-1}), T is the absolute temperature in K, and P is the cell pressure in atmospheres.

Nitric oxide is measured by bypassing the NO_2 scrubber and measuring the light intensity while adding (I) or not adding (I_o) ozone to convert NO to NO_2 according to the well-known reaction:

$$NO + O_3 \rightarrow NO_2 + O_2$$

As in all our instruments, a DewLine^{TM} Nafion® tube is used to equilibrate humidity during I and I_o measurements, so that any water vapour interference due to refractive effects on light transmission through the optical cell is eliminated.

NOx is computed from the measurement of NO and NO_2.

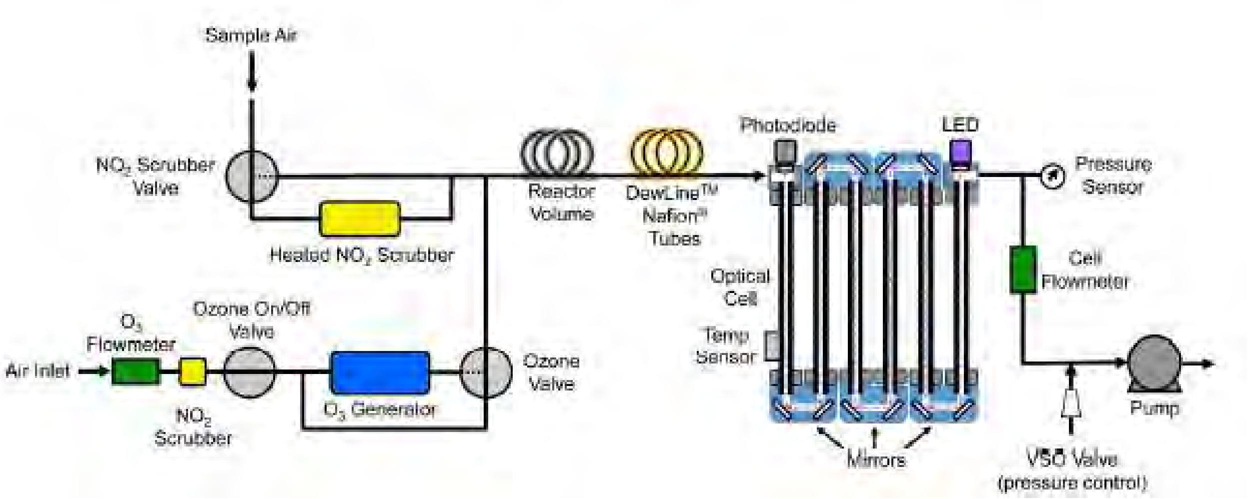


Figure 2: Flow schematic

3.2 AMS scope and set-up

The Model 405 nm nitrogen oxide monitor uses direct UV absorption for the continuous measurement of NO, NO_2 and NO_x in ambient air. The Modell 405nm system components include:

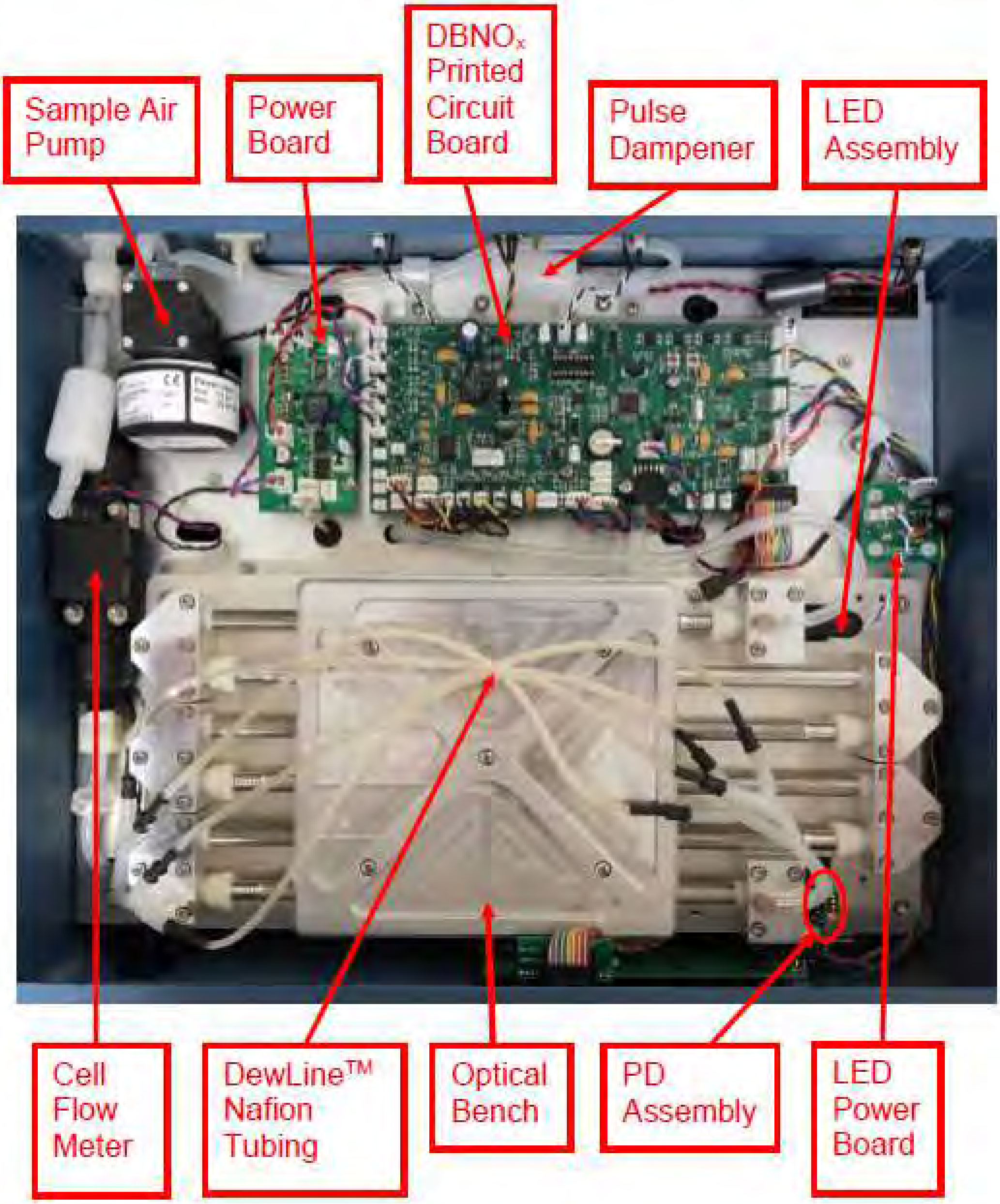


Figure 3: Inside view - top

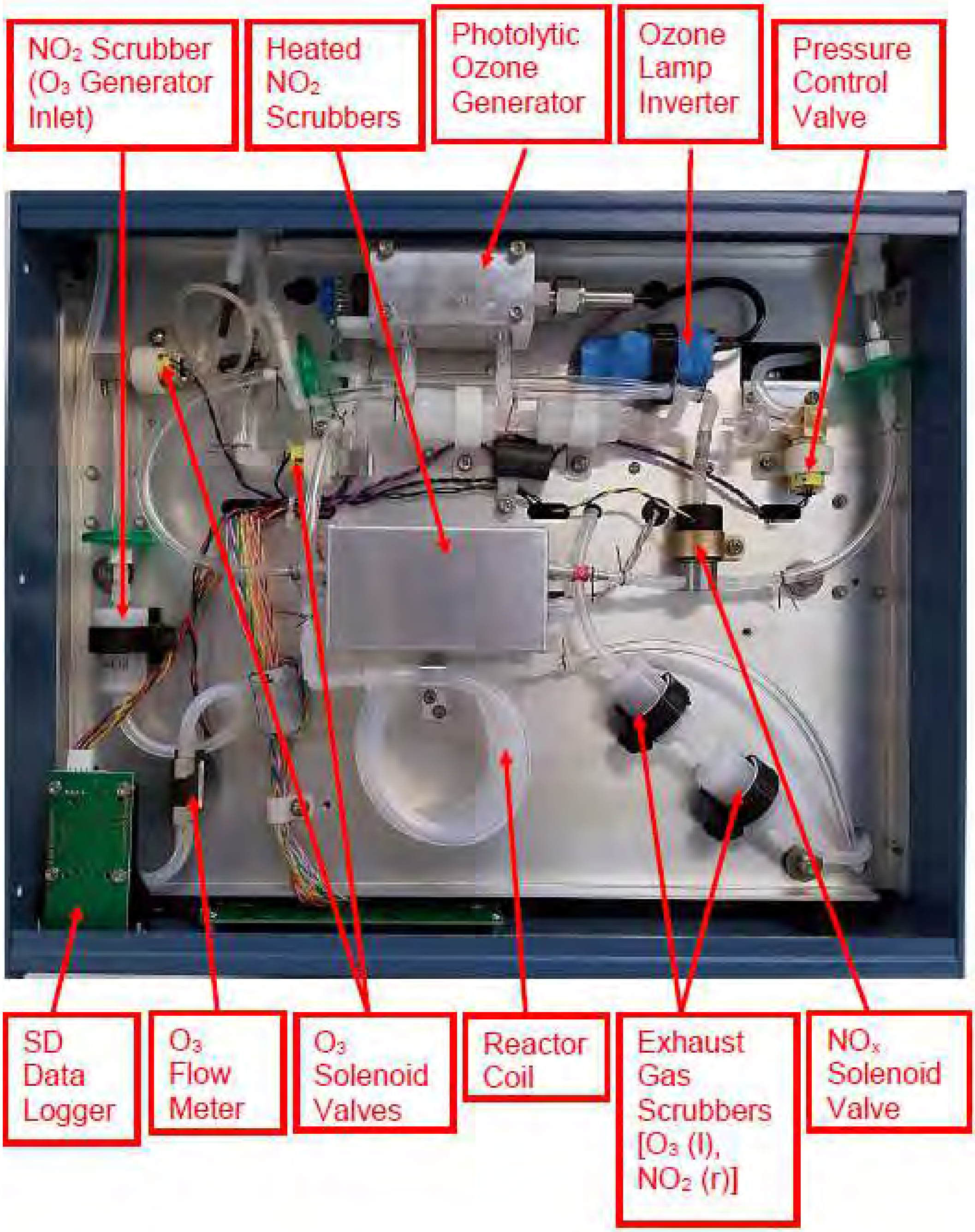


Figure 4: Inside view - bottom

Table 2 lists a number of important instrument characteristics of the Model 405 nm.

Table 2: Instrument specifications Model 405 nm (as provided by the manufacturer)

Measured range:	0–10 ppm max for NO_2 0–2 ppm max for NO
Units:	ppb or ppm
Measured compounds:	NO, NO_2 and NO_x
Sample flow rate	~1.5 l/min (during the test)
Outputs:	• SD chip • Serial interface, RS232 • 0–2.5 Volt analogue
Input voltage:	230 V or 115 V 50Hz or 60 Hz
Power:	17 W; 35 W max.
Dimension (l x w x h)	430 x 370 x 140 mm / ~ 9 kg

3.3 AMS adjustment

The measuring system was commissioned according to manufacturer instructions. No internal zero point adjustment cycles were activated during performance testing.

The Model 405 nm firmware processes sample concentration data through a built-in adaptive filter. During operation, the firmware may automatically switch between two different filter lengths based on the conditions at hand. During the measurement of stable concentrations, the firmware, by default, computes an average of the last 36 raw measurements, or 3 minutes of measurements. This will stabilise measuring results. If the filter detects rapid changes in concentration, the filter reduces the averaging to only 4 samples or 20 seconds to allow the analyser to respond more quickly. Two conditions must be simultaneously met to switch to the short filter. First, the instantaneous concentration must differ from the average in the long filter by at least 40 ppb. Second, the instantaneous concentration must differ from the average in the long filter by at least 10% of the average in the long filter. The mentioned equalisation filters were activated during the entire test.

4. Test programme

4.1 General remarks

Two identical Model 405 nm instruments with the following serial numbers were submitted to performance testing:

Instrument 1:	SN 1073 and
Instrument 2:	SN 1076

Software version “version 36B” was implemented during performance testing.

The test comprised a laboratory test to determine the performance characteristics as well as a field test over a period of several months.

In this report, the heading for each performance criterion cites the requirements according to the relevant standards ([1, 2, 3]) including its chapter number and wording.

Figure 5: Software version of the Model 405 nm test instruments

4.2 Laboratory test

The laboratory test was performed using two complete and identical systems type Model 405 nm, serial numbers 1073 and SN: 1076. Standards [1] and [2] specify the following test programme for the laboratory test:

- Description of instrument functions
- General requirements
- Calibration line fit
- Short-term drift
- Repeatability standard deviation
- Sensitivity to sample gas pressure
- Sensitivity to sample gas temperature
- Sensitivity to surrounding temperature
- Sensitivity to supply voltage
- Cross sensitivities
- Averaging effect
- Response time
- Difference sample/calibration inlet
- Converter efficiency

The measuring system does not use the EU standard reference method (chemiluminescence), but analyses NO_2 and NO alternately and directly using UV absorption as a measuring principle. The output for the NO_x value is always a calculated result. This is why NO and NO_2 were considered separately for every test item reported here. NO was tested in accordance with the requirements of EN 14211. For the purpose of testing NO_2 (tested measuring range 0–500 µg/m³ (0–261 nmol/mol)), test gas target values were adapted to the NO_2 measuring range. This, too, is specified in standard EN 14211. An additional cross-sensitivity test was performed for NO_2.

Measured values were recorded using an external data logger.

Chapters 6 and 7 summarizes the results of the laboratory tests.

4.3 Field test

The field test in accordance with EN 14211 and VDI 4202-1 was performed with two identical measuring systems type Model 405 nm in the period from July 23rd, 2018 to October 29th, 2018. Subsequently, the field test continued until February 1st, 2019 to collect further measurement data for the purpose of an evaluation in accordance with the Guide to the Demonstration of Equivalence of Ambient Air Monitoring Methods. The instruments used were identical with those used for laboratory testing. The serial numbers were:

instrument 1:	SN 1073
instrument 2:	SN 1076

The following test programme was determined for the field test:

- Long-term drift
- Period of unattended operation
- Availability
- Reproducibility standard deviation
- Converter efficiency (VDI 4202-1:2018)

As was the case during the laboratory test, the evaluation of field test results is presented separately for NO and NO_2.

Measured values were recorded using an external data logger.

Chapters 6 and 7 summarizes the results of the field tests.

5. Reference Measurement Method

5.1 Method of measurement

Test gases used for adjustment purposes during the test

Certified nitrogen monoxide and nitrogen dioxide test gases were used for the purpose of testing. The specified test gases were used during the entire test and, where necessary, were diluted with the help of a (type Hovacal) mass flow controller.

Test gas bottle (S/N 2003890) was traced back by the national EU reference laboratory for ambient air quality (Federal Environment Agency in Langen). Quality assurance of test gases used was based on the traceable test gas in the TÜV Rheinland Energy GmbH laboratory.

Zero gas:	**synthetic air**
Test gas NO:	**198.6 ppb in synth. air air**
Number of test gas cylinder:	2003890
Manufacturer / date of manufacture:	Linde / 04/07/2018
Stability guarantee / certified:	12 months
Checking of the certificate by / on:	25/07/2018 / UBA Langen Calibration certificate No. 039-2018
Measurement uncertainty as per calibration certificate:	+/- 4.0 nmol/mol
Test gas NO:	**1980 ppb in synth. air air**
Number of test gas cylinder:	16462
Manufacturer / date of manufacture:	Praxair / 19/03/2018
Stability guarantee / certified:	24 months
Certificate checked by:	Own laboratory
Rel. uncertainty according to certificate:	5%
Test gas NO_2:	**9.86 ppm ambient air**
Number of test gas cylinder:	16297
Manufacturer / date of manufacture:	Praxair / 22/02/2017
Stability guarantee / certified:	24 months
Certificate checked by:	Own laboratory
Rel. uncertainty according to certificate:	2%

Test results in accordance with VDI 4202, part 1 (2018)

6.1 7.3 General requirements

6.1 7.3.1 Measured value display

The measuring system shall have an operative measured value display as part of the instrument.

6.2 Equipment

No additional equipment is required.

6.3 Testing

It was checked whether the measuring system has a measured value display.

6.4 Evaluation

The measuring system has an operative measured value display at the instrument front.

6.5 Assessment

The measuring system has an operative measured value display at the instrument front.

Criterion satisfied? yes

6.6 Detailed presentation of test results

Figure 6 shows the measuring system with integrated measured value display.

Figure 6: Tested Model 405 nm instrument with measured value display

6.1 7.3.2 Calibration inlet

The measuring system may have a test gas inlet separate from the sample gas inlet.

6.2 Equipment

No additional equipment is required.

6.3 Testing

We tested whether the instrument includes a test gas inlet separate from the sample gas inlet.

6.4 Evaluation

The measuring system does not have a test gas inlet separate from the sample gas inlet. Test gas enters the measuring system via the sample gas inlet.

6.5 Assessment

The measuring system does not have a test gas inlet separate from the sample gas inlet. Test gas enters the measuring system via the sample gas inlet. Criterion satisfied? not applicable

6.6 Detailed presentation of test results

Not applicable in this instance.

6.1 7.3.3 Easy maintenance

Necessary maintenance of the measuring systems should be possible without larger effort, if possible from outside.

6.2 Equipment

No additional equipment is required.

6.3 Testing

The necessary regular maintenance was performed in accordance with the instruction manual.

6.4 Evaluation

The user is advised to perform the following maintenance activities:

1. Checking the operational status
   The operational status may be monitored and checked by visual inspections of the instrument's display or via an external PC connected to the AMS.
2. Checking and replacement of the external particle filter at the sample gas inlet The frequency at which the particle filter needs to be replaced depends on the dust concentrations in ambient air.

6.5 Assessment

Maintenance takes reasonable effort and is possible with standard tools from the outside.

Criterion satisfied? yes

6.6 Detailed presentation of test results

Maintenance was performed during the test in accordance with the activities and procedures described in the operation manual. Complying with the procedures described in the manual, no difficulties were identified. All maintenance activities were possible without any difficulties using standard tools.

6.1 7.3.4 Functional check

If the operation or the functional check of the measuring system require particular instruments, they shall be considered as part of the measuring system and be applied in the corresponding sub-tests and included in the assessment.
The performance of test gas generators, which are part of the measuring system, shall be checked by comparing it to the requirements for test gases used for continuous quality assurance. They have to provide a status signal indicating that they are ready for operation. It must be possible to control them directly or remotely.-

6.2 Equipment

Operation manual

6.3 Testing

The tested measuring system does not have internal devices for operating the functional check. The current operating status of the measuring system is continuously monitored and any issues will be flagged via a series of different error messages.

The functional check of the instruments was performed using external test gases.

6.4 Evaluation

The tested measuring system does not have internal devices for operating the functional check. The current operating status is continuously monitored and any issues will be flagged via a series of different warning messages.

External monitoring of the zero and reference point using test gases is possible.

6.5 Assessment

The tested measuring system does not have internal devices for operating the functional check.

Criterion satisfied? not applicable

6.6 Detailed presentation of test results

Not applicable.

6.1 7.3.5 Set-up times and warm-up times

The set-up times and warm-up-times shall be specified in the instruction manual.

6.2 Equipment

Operation manual and additional clock

6.3 Testing

The measuring systems were set up following the manufacturer's instructions. Set-up times and warm-up times were recorded separately.

Necessary constructional measures prior to the installation such as the installation of a sampling system in the analysis room were not taken into account.

6.4 Evaluation

The manual does not specify the set-up time. It will of course depend on the situation given at the site of installation as well as the local voltage supply. Since the Model 405 nm is a compact analyser, the set-up time is mainly determined by the following tasks:

- Connecting the AMS to supply voltage;
- Connecting the tubing (sampling, discharged air).

Commissioning and changing positions in the laboratory on various occasions (installation in/removal from the climatic chamber) as well as the installation at the field test location resulted in a set-up time of ~30 minutes.

When switching the AMS on in a completely cold state, it takes about 30 minutes to reach a stable reading. This value is also indicated in the operation manual.

The measuring system has to be installed at a location where it is protected from weather conditions, e.g. in an air-conditioned measurement container.

6.5 Assessment

Set-up times and warm-up times have been determined.

It is possible to operate the measuring system at different locations with limited effort. Set-up time is 30 minutes and warm-up time also amounts to about 30 minutes depending on the necessary stabilisation.

Criterion satisfied? yes

6.6 Detailed presentation of test results

Not applicable.

6.1 7.3.6 Instrument design

The instruction manual shall include specifications of the manufacturer regarding the design of the measuring system. The main elements are:
Instrument shape (e.g. bench mounting, rack mounting, free mounting)
Mounting position (e.g. horizontal or vertical mounting)
Safety requirements
Dimensions
Weight
Power consumption
Preventing condensation within the analyser.

6.2 Equipment

Operation manual and a measuring system for recording energy consumption (Gossen Metrawatt) and scales.

6.3 Testing

The instrument design of the measuring systems handed over for testing was compared to the description provided in the manual. The energy consumption specified was verified during normal operation in the field test.

6.4 Evaluation

The measuring system is intended for horizontal mounting (e.g. on a table or in a rack) sheltered from weather conditions. The temperature at the site of installation must be between 0 °C and 30 °C.

The dimensions and weight of the measuring system correspond to the information provided in the operation manual.

The manufacturer specifies a maximum power consumption of 35W. During start-up (warm-up) a short-term consumption of 32 W was recorded. During normal operation, energy consumption is 18 W.

6.5 Assessment

Specifications made in the instruction manual concerning instrument design are complete and correct.

Criterion satisfied? yes

6.6 Detailed presentation of test results

Not required for this performance criterion.

6.1 7.3.7 Unintended adjustment

It shall be possible to secure the adjustment of the measuring system against illicit or unintended adjustment during operation. Alternatively, the user manual shall specifically note that the measuring system may only be installed in a secured area.

6.2 Equipment

The test of this criterion did not require any further equipment.

6.3 Testing

The measuring system can be operated via a display with an operation button at its front with touch panel or via a PC connected to the measuring system directly or via a network.

6.4 Evaluation

The instrument does not provide an internal feature (password protection) to secure it against illicit or unintended adjustment. The NO/NO_2/NO_x monitor has to be installed inside a lockable measuring rack or container to protect it from unintended or unauthorised adjustment of instrument parameters. The operation manual of the measuring system communicates the special requirements regarding the site of installation.

6.5 Assessment

The measuring system is not secured against unintended and unauthorised adjustment of instrument parameters by way of a password. The NO/NO_2/NO_x monitor has to be installed inside a lockable measuring rack or container to protect it from unintended or unauthorised adjustment of instrument parameters. This is also indicated on page 6 of the operation manual.

Criterion satisfied? yes

6.6 Detailed presentation of test results

Not required for this performance criterion.

6.1 7.3.8 Data output

The output signal shall be provided digitally and/or as analogue signals (e.g. 4 mA to 20 mA).

6.2 Equipment

Analogue Yokogawa data logger, PC

6.3 Testing

The measuring system provides the following transmission routes: Serial interface, RS 232 and internal SD chip Moreover, the measuring system also provides an option to output analogue signals (0–2.5 Volt).

6.4 Evaluation

Measured signals are displayed on the back of the instrument as follows:

Analogue:	selectable concentration range of 0–2.5 V
Digital:	serial interface, RS232, internal SD chip

6.5 Assessment

Measured signals are output as analogue signals (0–2.5 V) and digital signals (via Modbus, RS 232).

The instrument provides additional interfaces (e.g. analogue outputs) for connecting additional measuring or other peripheral instruments.

Criterion satisfied? yes

6.6 Detailed presentation of test results

Not required for this performance criterion.

6.1 7.3.9 Digital interface

The digital interface shall allow the transmission of output signals, status signals, and information like instrument type, measurement range, and measured component and unit. The digital interface shall be described fully in respective standards and guidelines.
Access to the measuring system via digital interfaces, e.g. for data transmission, shall be secured against unauthorised access, e.g. by a password.

6.2 Equipment

PC

6.3 Testing

The measuring system provides the following transmission routes: Modbus, RS232. Moreover, the measuring system also provides an option to output analogue signals (in V).

6.4 Evaluation

Digital measured signals are provided as follows:

Modbus, RS232.

Digital output signals were checked. All relevant pieces of information such as measured signals, status signals, measured component, measuring range, unit and instrument information can be transmitted digitally.

6.5 Assessment

Digital transmission of measured values operates correctly.

Criterion satisfied? yes

6.6 Detailed presentation of test results

Not required for this performance criterion.

6.1 7.3.10 Data transmission protocol

The measuring system shall contain at minimum one data transmission protocol for the digital transmission of the output signal.
Every data transmission protocol provided by the manufacturer for the measuring system shall allow the correct transmission of the data and detect errors in the transmission. The data transmission protocol including the used commands is to be documented in the instruction manual. The data transmission protocol shall allow to transmit at minimum the following data:
identification of the measuring system
identification of measured components
Unit
output signal with time signature (date and time)
operation and error status
operating commands for remote control of the measuring systems

All data are to be transmitted as clear text (ASCII characters).

6.2 Equipment

PC

6.3 Testing

By default, the measuring system comes with an installed Modbus protocol.

6.4 Evaluation

By default, the measuring system comes with an installed Modbus protocol. Measured and status signals are transmitted correctly.

6.5 Assessment

By default, the measuring system comes with an installed Modbus protocol. Measured and status signals are transmitted correctly.

Criterion satisfied? yes

6.6 Detailed presentation of test results

Not required for this performance criterion.

6.1 7.3.11 Measuring range

The upper limit of measurement of the measuring systems shall be greater or equal to the upper limit of the certification range.

6.2 Equipment

The test of this criterion did not require any further equipment.

6.3 Testing

We compared the upper limit of measurement to the upper limit of the certification range to verify whether the former was larger or equal to the latter.

6.4 Evaluation

In theory, it is possible to set the measuring system to measuring ranges of up to 0–20 ppm.

Possible NO measuring ranges:	2 ppm
Possible NO_2 measuring range:	10 ppm
Upper limit of the certification range for NO:	1200 µg/m³ (962 ppb or nmol/mol)
Upper limit of the certification range for NO_2:	500 µg/m³ (261 ppb or nmol/mol)

6.5 Assessment

By default, the measuring range is set to 0–500 µg/m³ for NO_2 and 0–1200 µg/m³ for NO. Supplementary measuring ranges up to 0–2 and 10 ppm are possible.

The measuring system's upper limit of measurement exceeds the upper limit of the certification range in each case.

Criterion satisfied? yes

6.6 Detailed presentation of test results

VDI Guideline 4202, part 1 and standard EN 14211 define the following minimum requirements for the certification ranges of continuous air quality monitoring systems for nitrogen oxides:

Table 3: Certification ranges VDI 4202-1 and EN 14211

Measured components:	CR lower limit	CR upper limit	Limit value	Evaluation period
	in µg/m³	in µg/m³	in µg/m³	
Nitrogen dioxide	0	500	200	1 h
Nitrogen monoxide	0	1 200	631.3 *)	1 h

* No limit value is defined for NO. Standard EN 14211 recommends to use a value of 500 ± 50 nmol/mol instead.

6.1 7.3.12 Negative output signals

Negative output signals or measured values may not be suppressed (life zero).

6.2 Equipment

The test of this criterion did not require any further equipment.

6.3 Testing

The possibility of displaying negative signals was tested both in the laboratory and in the field test.

6.4 Evaluation

The AMS displays negative values.

6.5 Assessment

The measuring system also provides negative output signals.

Criterion satisfied? yes

6.6 Detailed presentation of test results

Not applicable.

6.1 7.3.13 Failure in the mains voltage

In case of malfunction of the measuring system or failure in the mains voltage uncontrolled emission of operation and calibration gas shall be avoided. The measurement parameters shall be secured by buffering against loss caused by failure in the mains voltage. When mains voltage returns, the instrument shall automatically reach the operation mode and start the measurement according to the operating instructions.

6.2 Equipment

Not required for this performance criterion

6.3 Testing

A simulated failure in the mains voltage served to test whether the instrument remained fully functional and reached operation mode on return of the mains voltage.

6.4 Evaluation

Since the measuring systems do not rely on operation and calibration gases, uncontrolled emission of gases is not possible.

Once the measuring system resumes operation after a power failure it is in warm-up mode until it reaches an appropriate operating temperature again. How long it will take up to fully warm up again will depend on the ambient conditions and the temperature of the system when switching it back on again. After completion of the warm-up phase, the measuring system will switch back automatically into the mode which had been active before the failure in mains voltage. A status signal is displayed during warm-up.

6.5 Assessment

On return of mains voltage, the instrument returns to normal operating mode after a warm-up phase and automatically resumes measuring.

Criterion satisfied? yes

6.6 Detailed presentation of test results

Not applicable.

6.1 7.3.14 Operating states

The measuring system shall allow the control of important operating states by telemetrically transmitted status signals.

6.2 Equipment

Computer for data acquisition

6.3 Testing

The measuring system provides various interfaces such as RS232 and analogue outputs. It is possible to establish a simple serial connection between the analyser and an external PC. This enables telemetrically transferring data, adjusting configurations and displaying the analyser reading on the computer screen. In this mode it is possible to access and operate all the information and features from the analyser display via the computer. Moreover, “remote operation” provides a useful tool for checking instrument operational and parameter values.

6.4 Evaluation

The measuring system allows for comprehensive monitoring and control via various connectors.

6.5 Assessment

The measuring system provides various ports to ensure comprehensive monitoring and control via an external computer.

Criterion satisfied? yes

6.6 Detailed presentation of test results

Not applicable.

6.1 7.3.15 Switch-over

Switch-over between measurement and functional check and/or calibration shall be possible telemetrically by computer control or manual intervention.

6.2 Equipment

Not required for this performance criterion

6.3 Testing

It is not possible to directly control the measuring system telemetrically. For remote monitoring of the measuring system, an external PC hat to be connected to the measuring system which can then be monitored and controlled via an internet connection. It is possible to monitor and control the AMS on the instrument itself or telemetrically via an external PC connected to the instrument.

6.4 Evaluation

All operating and monitoring procedures which do not require on-site practical handling may be performed both by the operator on the instrument itself or telemetrically via a connected PC with internet connection.

6.5 Assessment

In principle, it is possible to perform all necessary activities in the context of functional testing on the instrument itself or remotely with the help of an external PC connected to the internet.

Criterion satisfied? yes

6.6 Detailed presentation of test results

Not applicable.

6.1 7.3.16 Instrument software

The measuring system shall be able to display the version of the instrument software.

6.2 Equipment

Not required for this performance criterion

6.3 Testing

It was tested whether the software version can be displayed on the instrument. The AMS manufacturer was informed of his obligation to communicate any changes to the instrument software to the test laboratory.

6.4 Evaluation

The current software version is displayed when switching on the instrument. Furthermore, it can be accessed via menu item “configuration” at any time.

The tests were performed with software version “36B”.

6.5 Assessment

The instrument’s software version is displayed. Software changes are communicated to the test laboratory.

Criterion satisfied? yes

6.6 Detailed presentation of test results

Figure 5 shows the software version displayed by the measuring system.

6.1 7.4 Requirements on performance characteristics in the laboratory

6.1 7.4.1 General requirements

The performance characteristics which shall be determined during testing in the laboratory and their related performance criteria for measured components according to 39. BImSchV are given in Table A1 of VDI 4202-1.
The certification range for other components is to be defined. Performance criteria are to be defined by drawing from Table A1 of standard VDI 4202-1 (2018). These definitions shall be cleared with the relevant body before testing.
The determination of the performance characteristics shall be done according to the procedures de-scribed in Section 8.4.

6.2 Equipment

Not required for this performance criterion

6.3 Testing

Tests were performed using the performance characteristics specified in VDI standard 4202, part 1 (2018) and standard EN 14211.

6.4 Evaluation

Not applicable.

6.5 Assessment

Tests were performed using the performance characteristics specified in VDI standard 4202, part 1 (2018) and standard EN 14211 (2012)

Criterion satisfied? yes

6.6 Detailed presentation of test results

Not applicable.

6.1 7.4.2 Test requirements

Before operating the measuring system, the instruction manual of the manufacturer shall be followed particularly with regard to the set-up of equipment and the quality and quantity of the consumable supplies necessary.

The measuring system shall be allowed to warm up for the duration specified by the manufacturer be-fore undertaking any tests. If the warm-up time is not specified, a minimum of 4 h applies.

If auto-scale or self-correction functions are arbitrary, these functions shall be turned off during the laboratory test.

If auto-scale or self-correction functions are not arbitrary but treated as “normal operating conditions”, times and values of the self-correction shall be available for the test laboratory. The values of the auto-zero and auto-drift corrections are subject to the same restrictions as given in the performance characteristics.

Before applying test gases to the measuring sys-tem, the test gas system shall have been operated for a sufficiently long time in order to stabilize the concentrations applied to the measuring system. The measuring system shall be tested using an implemented particle filter.

Most measuring systems are able to display the output signal as running average of an adjustable period. Some measuring systems adjust the integration time as a function of the frequency of the fluctuations of the concentration of the measured component automatically. These options are typically used for equalisation of the output data It does not have to be proved that the selected value for the averaging period or the use of an active filter affects the result of testing the averaging period and the response time.

The adjustments of the measuring system shall meet the specifications of the manufacturer. All adjustments are to be documented in the test report.

For the determination of the various performance characteristics, suitable zero and test gases shall be used.

Parameters: During the test for each individual performance characteristic, the values of the following parameters shall be stable within the specified range given in Table 3 of standard VDI 4202-1.

Test gas: For the determination of the various performance characteristics, test gases traceable to national or international standards shall be used.

6.2 Equipment

Not required for this performance criterion

6.3 Testing

Tests were performed using the performance characteristics specified in VDI standard 4202, part 1 (2018) and standard EN 14211.

6.4 Evaluation

The warm-up time described in the manual was observed.

Neither auto-scale nor self-correction functions were activated during the laboratory test.

The tests were performed with the internal upstream particle filters.

As described in section 3.3, the equalisation filters were activated during the entire test period.

Test gases used comply with the requirements of VDI 4202-1.

6.5 Assessment

Tests were performed using the performance characteristics specified in VDI standard 4202, part 1 (2018) and standard EN 14211 (2012)

Criterion satisfied? yes

6.6 Detailed presentation of test results

Not applicable.

6.1 7.4.3 Response time and memory effect

The response time (rise) of the measuring system shall not exceed 180 s.

The response time (fall) of the measuring system shall not exceed 180 s.

The difference between the response time (rise) and response time (fall) of the measuring system shall not exceed 10% of response time (rise) or 10 s, whatever value is larger.

6.2 Equipment

Not applicable

6.3 Testing

Determination and evaluation of the response time corresponds exactly to determining the response time in accordance with standard EN 14211 (2012). The reader is therefore referred to chapter 7.1 8.4.3 Response time.

6.4 Evaluation

See chapter 7.1 8.4.3 Response time

6.5 Assessment

See chapter 7.1 8.4.3 Response time
Criterion satisfied? yes

6.6 Detailed presentation of test results

Not applicable in this instance.

6.1 7.4.4 Short-term drift

The short-term drift at zero point shall not exceed 2.0 nmol/mol.
The short-term drift at reference point shall not exceed 6.0 nmol/mol.

6.2 Equipment

Not applicable

6.3 Testing

Determination and evaluation of the short-term drift corresponds exactly to determining the short term drift in accordance with standard EN 14211 (2012). The reader is therefore referred to chapter 7.1 8.4.4 Short-term drift.

6.4 Evaluation

See chapter7.1 8.4.4 Short-term drift

6.5 Assessment

See chapter 7.1 8.4.4 Short-term drift
Criterion satisfied? yes

6.6 Detailed presentation of test results

Not applicable in this instance.

6.1 7.4.5 Repeatability standard deviation

The repeatability standard deviation at zero point shall be ≤ 1.0 nmol/mol of the upper limit of the certification range.
The repeatability standard deviation at reference point shall not exceed 3.0 nmol/mol.

6.2 Equipment

Not applicable

6.3 Testing

Performing and evaluating the repeatability standard deviation at zero point corresponds exactly to determining the repeatability standard deviation in accordance with standard EN 14211 (2012). The reader is therefore referred to chapter 7.1 8.4.5 Repeatability standard deviation.

6.4 Evaluation

See chapter 7.1 8.4.5 Repeatability standard deviation.

6.5 Assessment

See chapter REF _Ref350855257 \h 7.1 8.4.5 Repeatability standard deviation

Criterion satisfied? yes

6.6 Detailed presentation of test results

Not applicable in this instance.

6.1 7.4.6 Linearity

The analytical function describing the relationship between the measured values and the desired values shall be linear. Reliable linearity is
The deviation from the linearity of the calibration function at zero shall not exceed 5 nmol/mol. At concentrations above zero, it shall not exceed 4% of the measured value.

6.2 Equipment

Not applicable

6.3 Testing

Performing and evaluating the linearity corresponds exactly to determining the lack of fit in accordance with standard EN 14211 (2012). The reader is therefore referred to chapter 7.1 8.4.6 Lack of fit of linearity of the calibration function.

6.4 Evaluation

See chapter 7.1 8.4.6 Lack of fit of linearity of the calibration function.

6.5 Assessment

See chapter 7.1 8.4.6 Lack of fit of linearity of the calibration function.

Criterion satisfied? yes

6.6 Detailed presentation of test results

Not applicable in this instance.

6.1 7.4.7 Sensitivity coefficient to sample gas pressure

The sensitivity coefficient of sample gas pressure at reference point shall not exceed 8.0 (nmol/mol)/kPA.

6.2 Equipment

Not applicable

6.3 Testing

Performing and evaluating the sensitivity coefficient of sample gas pressure corresponds exactly to determining the sensitivity coefficient to sample gas pressure in accordance with standard EN 14211 (2012). The reader is therefore referred to chapter 7.1 8.4.7 Sensitivity coefficient to sample gas pressure.

6.4 Evaluation

See chapter 7.1 8.4.7 Sensitivity coefficient to sample gas pressure

6.5 Assessment

See chapter 7.1 8.4.7 Sensitivity coefficient to sample gas pressure

Criterion satisfied? yes

6.6 Detailed presentation of test results

Not applicable in this instance.

6.1 7.4.8 Sensitivity coefficient to sample gas temperature

The sensitivity coefficient of sample gas temperature shall not exceed 3.0 (nmol/mol)/kPA.

6.2 Equipment

Not applicable

6.3 Testing

Performing and evaluating the sensitivity coefficient of sample gas temperature corresponds exactly to determining the sensitivity coefficient to sample gas temperature in accordance with standard EN 14211 (2012). The reader is therefore referred to chapter 8.4.8 Sensitivity coefficient to sample gas temperature.

6.4 Evaluation

See chapter 8.4.8 Sensitivity coefficient to sample gas temperature

6.5 Assessment

See chapter 8.4.8 Sensitivity coefficient to sample gas temperature

Criterion satisfied? yes

6.6 Detailed presentation of test results

Not applicable in this instance.

6.1 7.4.9 Sensitivity coefficient to surrounding temperature

The sensitivity coefficient of surrounding temperature shall not exceed 3.0 (nmol/mol)/kPA.

6.2 Equipment

Not applicable

6.3 Testing

Performing and evaluating the sensitivity coefficient of surrounding temperature corresponds exactly to determining the sensitivity coefficient to the surrounding temperature in accordance with standard EN 14211 (2012). The reader is therefore referred to chapter 7.1 8.4.9 Sensitivity coefficient to surrounding temperature.

6.4 Evaluation

See chapter7.1 8.4.9 Sensitivity coefficient to surrounding temperature

6.5 Assessment

See chapter7.1 8.4.9 Sensitivity coefficient to surrounding temperature

Criterion satisfied? yes

6.6 Detailed presentation of test results

Not applicable in this instance.

6.1 7.4.10 Sensitivity coefficient to electrical voltage

The sensitivity coefficient of electrical voltage shall not exceed 0.3 (nmol/mol)/V.

6.2 Equipment

Not applicable

6.3 Testing

Performing and evaluating the sensitivity coefficient of electrical voltage corresponds exactly to determining the sensitivity coefficient to electrical voltage in accordance with standard EN 14211 (2012). The reader is therefore referred to chapter 7.1 8.4.10 Sensitivity coefficient to electrical voltage.

6.4 Evaluation

See chapter 7.1 8.4.10 Sensitivity coefficient to electrical voltage

6.5 Assessment

See chapter 7.1 8.4.10 Sensitivity coefficient to electrical voltage

Criterion satisfied? yes

6.6 Detailed presentation of test results

Not applicable in this instance.

6.1 7.4.11 Cross sensitivity

The change in the measured value caused by interfering components in the sample gas shall not exceed the requirements of Table A of VDI 4202, part 1 (April 2018), at zero and reference point.

For measuring principles deviating from EN standards the absolute values of the sum of the positive and the sum of negative deviations caused by interfering components in the sample gas shall not exceed 3% of the upper limit of the certification range at zero and reference point. A value c_t at 70% to 80% of the upper limit of the certification range shall be used as reference point.

6.2 Equipment

Not applicable

6.3 Testing

The measuring system does not use the reference method chemiluminescence but measures NO_3 directly instead. Performance and evaluation of cross-sensitivity tests in accordance with EN 14211 (2012) and VDI 4202-1 (2018) was aligned with the reference method regarding the selection of cross-sensitivity components. This why, in addition to the three interfering substances specified in EN 14211, further interferents potentially present in ambient air were tested for their effects. As the measuring system analyses sample air in the UV range, additional interferents were only considered where they had optical absorption lines in the UV range. Additionally tested interferences included SO_2, H_2S, m-xylene and toluene.

Section 7.1 8.4.11 Interferents presents the results of performing and evaluating cross-sensitivity tests in accordance with EN 14211 (2012). The uncertainty contribution of cross-sensitivities is also determined from the tests which fully comply with EN 14211.

6.4 Evaluation

The following table summarises differences with and without interfering components for the zero and reference points of the analysers. The table below sums up the positive and negative sums of the deviations. The assessment also includes the interferents specified by EN 14211 (H_2S, CO_2 and NH_3). Test gas concentration levels were selected in accordance with VDI standard 4201-1 (2018). The concentration level of interferents was selected on the basis of ´VDI 4202-1 (2018). For the component SO_2, a 1-hour limit value was selected.

Table 4: Additional cross sensitivities for the component NO, system 1

AMS: Model 405nm
Component: NO (certification range = 0 - 962 nmol/mol)

	AMS 1							
	Zero point				Span point			
Interferent	Nominal value nmol/mol	Reading nmol/mol	%TG	Deviation nmol/mol	Nominal value nmol/mol	Reading nmol/mol	%TG	Deviation nmol/mol
SO_2 131 nmol/mol	0.43	1.13	≤ 0.50	0.70	701.49	701.30	≤ 0.50	-0.19
H_2S 200 nmol/mol	0.83	1.00	≤ 0.50	0.17	700.37	700.65	≤ 0.50	0.28
CO_2 500 µmol/mol	-0.27	1.00	≤ 0.50	1.27	697.87	697.78	≤ 0.50	-0.09
m-Xylol 1 µmol/mol	0.47	0.37	≤ 0.50	-0.10	700.61	701.16	≤ 0.50	0.55
Toluol 0.5 µmol/mol	0.63	0.23	≤ 0.50	-0.40	702.92	703.34	≤ 0.50	0.42
H_2O 19 mmol/mol	-0.47	1.40	≤ 0.50	1.87	701.58	704.82	≤ 0.50	3.24
NH_3 200 nmol/mol	0.40	1.77	≤ 0.50	1.37	701.39	704.36	≤ 0.50	2.97
Sum of positive deviations				**5.38**				**7.46**
Sum of negative deviations				**-0.50**				**-0.28**

Table 5: Additional cross sensitivities for the component NO, system 2

AMS: Model 405nm
Component: NO (certification range = 0 - 962 nmol/mol)

	AMS 2							
	Zero point				Span point			
Interferent	Nominal value nmol/mol	Reading nmol/mol	%TG	Deviation nmol/mol	Nominal value nmol/mol	Reading nmol/mol	%TG	Deviation nmol/mol
SO_2 131 nmol/mol	0.33	0.37	≤ 0.50	0.04	703.99	703.90	≤ 0.50	-0.09
H_2S 200 nmol/mol	0.53	0.73	≤ 0.50	0.20	699.40	699.36	≤ 0.50	-0.04
CO_2 500 µmol/mol	0.27	1.30	≤ 0.50	1.03	699.96	699.49	≤ 0.50	-0.47
m-Xylol 1 µmol/mol	0.67	0.50	≤ 0.50	-0.17	702.69	703.76	≤ 0.50	1.07
Toluol 0.5 µmol/mol	0.60	0.60	≤ 0.50	0.00	701.44	702.00	≤ 0.50	0.56
H_2O 19 mmol/mol	0.63	0.97	≤ 0.50	0.34	697.87	701.76	0.56	3.89
NH_3 200 nmol/mol	0.17	1.83	≤ 0.50	1.66	703.94	705.29	≤ 0.50	1.35
Sum of positive deviations				**3.27**				**6.87**
Sum of negative deviations				**-0.17**				**-0.60**

Table 6: Additional cross sensitivities for the component NO_2, system 1

AMS: Model 405nm
Component: NO2 (certification range = 0 - 261 nmol/mol)

Interferent	AMS 1							
	Zero point				Span point			
	Nominal value nmol/mol	Reading nmol/mol	%TG	Deviation nmol/mol	Nominal value nmol/mol	Reading nmol/mol	%TG	Deviation nmol/mol
SO_2 131 nmol/mol	0.40	0.50	≤ 0.50	0.10	190.87	191.91	0.54	1.04
H_2S 200 nmol/mol	0.40	0.57	≤ 0.50	0.17	193.75	193.75	≤ 0.50	0.00
CO_2 500 µmol/mol	0.47	0.40	≤ 0.50	-0.07	191.91	190.87	– 0.54	-1.04
m-Xylol 1 µmol/mol	0.23	0.57	≤ 0.50	0.34	192.10	191.61	≤ 0.50	-0.49
Toluol 0.5 µmol/mol	0.57	0.53	≤ 0.50	-0.04	191.36	191.48	≤ 0.50	0.12
H_2O 19 mmol/mol	0.37	0.43	≤ 0.50	0.06	193.94	197.49	1.83	3.55
NH_3 200 nmol/mol	0.47	1.43	0.51	0.96	188.72	190.26	0.82	1.54
Sum of positive deviations				**1.63**				**6.25**
Sum of negative deviations				**-0.11**				**-1.53**

Table 7: Additional cross sensitivities for the component NO_2, system 2

AMS: Model 405nm
Component: NO2 (certification range = 0 - 261 nmol/mol)

Interferent	AMS 2							
	Zero point				Span point			
	Nominal value nmol/mol	Reading nmol/mol	%TG	Deviation nmol/mol	Nominal value nmol/mol	Reading nmol/mol	%TG	Deviation nmol/mol
SO_2 131 nmol/mol	0.37	0.53	≤ 0.50	0.16	193.32	192.89	≤ 0.50	-0.43
H_2S 200 nmol/mol	0.57	0.37	≤ 0.50	-0.20	191.73	191.36	≤ 0.50	-0.37
CO_2 500 µmol/mol	0.27	0.33	≤ 0.50	0.06	190.13	190.81	≤ 0.50	0.68
m-Xylol 1 µmol/mol	0.63	0.43	≤ 0.50	-0.20	194.61	193.20	– 0.72	-1.41
Toluol 0.5 µmol/mol	0.77	0.63	≤ 0.50	-0.14	193.38	194.00	≤ 0.50	0.62
H_2O 19 mmol/mol	0.10	0.33	≤ 0.50	0.23	192.28	196.21	2.04	3.93
NH_3 200 nmol/mol	0.60	1.33	≤ 0.50	0.73	192.65	194.12	0.76	1.47
Sum of positive deviations				**1.18**				**6.70**
Sum of negative deviations				**-0.54**				**-2.21**

6.5 Assessment

For measuring principles deviating from EN standards the absolute values of the sum of the positive and the sum of negative deviations caused by interfering components in the sample gas shall not exceed 3% of the upper limit of the certification range at zero and reference point. For a measuring range of 0–962 nmol/mol, this results in a permissible deviation of 28.86 nmol/mol for the component NO. For NO_2, the permissible deviation in the measuring range 0–261 nmol/mol is at 7.83 nmol/mol. As presented in Tables 4 to 7, this limits are clearly adhered to.

The influence of cross-sensitivities complies with the requirements of VDI 4202-1 (2018) for measuring principles which differ from those defined in EN standards.

Criterion satisfied? yes

6.6 Detailed presentation of test results

The following tables present individual values of the cross-sensitivities performed.

Table 8: Additional cross sensitivities for the component NO, system 1

Measuring system: Model 405nm
Component NO (certification range = 0–962 nmol/mol)
Measurement date: 27/06/2018 to 02/07/2018

System 1			Zero point				
Interferent			Nominal value nmol/mol	1. nmol/mol	2. nmol/mol	3. nmol/mol	∅ nmol/mol
SO_2	131	nmol/mol	0.43	1.20	1.20	1.00	1.13
H_2S	200	nmol/mol	0.83	0.70	0.90	1.40	1.00
CO_2	500	µmol/mol	-0.27	0.70	0.90	1.40	1.00
m-Xylene	1	µmol/mol	0.47	-0.10	1.00	0.20	0.37
Toluene	0.5	µmol/mol	0.63	0.90	0.10	-0.30	0.23
H_2O	19	mmol/mol	-0.47	1.80	1.30	1.10	1.40
NH_3	200	nmol/mol	0.40	1.80	1.70	1.80	1.77

System 1			Reference point				
Interferent			Nominal value nmol/mol	1. nmol/mol	2. nmol/mol	3. nmol/mol	∅ nmol/mol
SO_2	131	nmol/mol	701.49	701.39	701.81	700.70	701.30
H_2S	200	nmol/mol	700.37	700.70	700.42	700.84	700.65
CO_2	500	µmol/mol	697.87	697.36	697.64	698.34	697.78
m-Xylene	1	µmol/mol	700.61	700.98	701.53	700.98	701.16
Toluene	0.5	µmol/mol	702.92	702.51	703.90	703.62	703.34
H_2O	19	mmol/mol	701.58	705.98	704.59	703.90	704.82
NH3	200	nmol/mol	701.39	703.90	704.73	704.45	704.36

Table 9: Additional cross sensitivities for the component NO, system 2

Measuring system: Model 405nm
Component NO (certification range = 0–962 nmol/mol)
Measurement date: 27/06/2018 to 02/07/2018

System 2			Zero point				
Interferent			Nominal value nmol/mol	1. nmol/mol	2. nmol/mol	3. nmol/mol	∅ nmol/mol
SO_2	131	nmol/mol	0.33	0.10	0.10	0.90	0.37
H_2S	200	nmol/mol	0.53	-0.20	0.60	1.80	0.73
CO_2	500	µmol/mol	0.27	1.40	1.60	0.90	1.30
m-Xylene	1	µmol/mol	0.67	0.90	0.50	0.10	0.50
Toluene	0.5	µmol/mol	0.60	0.40	0.70	0.70	0.60
H_2O	19	mmol/mol	0.63	0.90	0.90	1.10	0.97
NH_3	200	nmol/mol	0.17	1.80	2.10	1.60	1.83

System 2			Reference point				
Interferent			Nominal value nmol/mol	1. nmol/mol	2. nmol/mol	3. nmol/mol	∅ nmol/mol
SO_2	131	nmol/mol	703.99	703.62	703.76	704.31	703.90
H_2S	200	nmol/mol	699.40	698.75	699.31	700.00	699.36
CO_2	500	µmol/mol	699.96	699.03	699.73	699.73	699.49
m-Xylene	1	µmol/mol	702.69	703.76	703.62	703.90	703.76
Toluene	0.5	µmol/mol	701.44	702.23	701.53	702.23	702.00
H_2O	19	mmol/mol	697.87	701.26	702.23	701.81	701.76
NH_3	200	nmol/mol	703.94	705.29	705.70	704.87	705.29

Table 10: Additional cross sensitivities for the component NO_2, system 1

Measuring system: Model 405nm
Component NO_2 (certification range = 0–261 nmol/mol)
Measurement date: 27/06/2018 to 02/07/2018

System 1			Zero point				
Interferent			Nominal value nmol/mol	1. nmol/mol	2. nmol/mol	3. nmol/mol	∅ nmol/mol
SO_2	131	nmol/mol	0.40	0.90	0.00	0.60	0.50
H_2S	200	nmol/mol	0.40	0.20	0.60	0.90	0.57
CO_2	500	µmol/mol	0.47	0.30	0.00	0.90	0.40
m-Xylene	1	µmol/mol	0.23	0.50	0.80	0.40	0.57
Toluene	0.5	µmol/mol	0.57	0.70	0.40	0.50	0.53
H_2O	19	mmol/mol	0.37	0.30	0.30	0.70	0.43
NH_3	200	nmol/mol	0.47	1.40	1.50	1.40	1.43

System 1			Reference point				
Interferent			Nominal value nmol/mol	1. nmol/mol	2. nmol/mol	3. nmol/mol	∅ nmol/mol
SO_2	131	nmol/mol	190.87	192.28	191.91	191.54	191.91
H_2S	200	nmol/mol	193.75	193.75	193.20	194.30	193.75
CO_2	500	µmol/mol	191.91	189.89	191.36	191.36	190.87
m-Xylene	1	µmol/mol	192.10	191.91	191.36	191.54	191.61
Toluene	0.5	µmol/mol	191.36	191.54	190.81	192.10	191.48
H_2O	19	mmol/mol	193.94	197.06	197.98	197.43	197.49
NH_3	200	nmol/mol	188.72	189.52	190.07	191.18	190.26

Table 11: Additional cross sensitivities for the component NO_2, system 2

Measuring system: Model 405nm
Component NO_2 (certification range = 0–261 nmol/mol)
Measurement date: 27/06/2018 to 02/07/2018

System 2			Zero point				
Interferent			Nominal value nmol/mol	1. nmol/mol	2. nmol/mol	3. nmol/mol	∅ nmol/mol
SO_2	131	nmol/mol	0.37	0.60	0.80	0.20	0.53
H_2S	200	nmol/mol	0.57	0.00	0.80	0.30	0.37
CO_2	500	µmol/mol	0.27	0.30	0.30	0.40	0.33
m-Xylene	1	µmol/mol	0.63	0.20	0.50	0.60	0.43
Toluene	0.5	µmol/mol	0.77	0.70	0.80	0.40	0.63
H_2O	19	mmol/mol	0.10	0.60	0.10	0.30	0.33
NH_3	200	nmol/mol	0.60	1.00	1.60	1.40	1.33

System 2			Reference point				
Interferent			Nominal value nmol/mol	1. nmol/mol	2. nmol/mol	3. nmol/mol	∅ nmol/mol
SO_2	131	nmol/mol	193.32	192.83	192.83	193.02	192.89
H_2S	200	nmol/mol	191.73	191.73	191.36	190.99	191.36
CO_2	500	µmol/mol	190.13	190.81	190.62	190.99	190.81
m-Xylene	1	µmol/mol	194.61	192.83	193.38	193.38	193.20
Toluene	0.5	µmol/mol	193.38	194.30	193.94	193.75	194.00
H_2O	19	mmol/mol	192.28	196.51	196.14	195.96	196.21
NH_3	200	nmol/mol	192.65	194.12	193.57	194.67	194.12

6.1 7.4.12 Averaging effect

The measuring system shall enable hourly averages.

The averaging effect shall not exceed 7% of the measured value.

6.2 Equipment

Test gases, mixing station

6.3 Testing

The averaging test gives a measure of the uncertainty in the averaged values caused by short-term concentration variations in the sampled air shorter than the time scale of the measurement process in the analyser. In general, the output of an analyser is a result of the determination of a reference concentration (normally zero) and the actual concentration which takes a certain time.

For the determination of the uncertainty due to the averaging, the following concentrations are applied to the analyser and readings are taken at each concentration:

- a constant concentration of NO_2 at a concentration $c_{t,}NO_2$ which is about twice the hourly limit value; and
- a stepwise varied concentration of NO between zero and 600 nmol/mol (concentration $c_{t,NO}$).

The time period (t_c) of the constant NO concentration shall be at least equal to a period necessary to obtain four independent readings (equal to a minimum of 16 response times). The time period (t_v) for the changed NO concentration must be at least equal to the time period necessary to obtain four independent readings (t_{NO}). The NO concertation must be fed 45 s followed by the time period (t_{zero}) of 45 s for the zero concentration. Further:

c_t is the test concentration;

t_v is a time period including a whole number of t_{NO} and t_{zero} pairs, and contains a minimum of 3 such pairs.

The change from t_{NO} to t_{zero} shall be within 0.5 s. The change from t_C to t_V shall be within one response time of the analyser under test.

The averaging effect is calculated as follows:

$$E_{av} = \frac{C_{const}^{av} - 2C_{\text{var}}^{av}}{C_{const}^{av}} * 100$$

Where:

E_{av} is the averaging effect (%);

C_{const}^{av} is the average of the at least four independent measurements during the variable concentration period;

C_{var}^{av} 0x1is the average of the at least four independent measurements during the variable concentration period;

A different procedure applies to NO_2

The averaging effect shall be determined for the components NO_2 and NO. The averaging effect for NO shall be computed in accordance with EN 14211. By contrast, the averaging effect for NO_2 shall be computed on the basis of the following equation.

$$E_{av}\frac{C_{const}^{av}-C_{var}^{av}}{C_{const}^{av}}*100\%$$

Where:

E_{av}	is the averaging effect (%);
C_{const}^{av}	is the average of the at least four independent measurements during the variable concentration period;
C_{var}^{av}	0x1is the average of the at least four independent measurements during the variable concentration period;

The averaging test was performed in compliance with the requirements specified in EN 14211 and in VDI 4202-1. With the help of a mass flow controller we applied a step change of the NO concentration between zero and 600 nmol/mol and, at the same time, a constant NO_2 concentration $c_{t,}NO_2$ of roughly twice the hourly limit value. First, the average was calculated at a constant test gas concentration. Then, a three-way valve served to switch between zero and test gas every 45 s. During that period of alternating test gas application the average was calculated again.

6.4 Evaluation

The following averages were determined during the test:

Table 12: Results of the averaging test for NO

	requirement	device 1		device 2	
averaging effect E_{av} [%]	≤ 7%	0.5	✓	3.8	✓

This results in the following averaging effects for NO:

System 1 0.5%

System 2 3.8%

Evaluation for the component NO_2 during the test of NO as described above:

Table 13: Results of the averaging test for NO_2

	requirement	device 1		device 2	
averaging effect E_{av} [%]	≤ 7%	1.9	✓	2.3	✓

This results in the following averaging effects for NO_2:

System 1 1.9%

System 2 2.3%

6.5 Assessment

The performance criterion specified in standards VDI 4202-1 and EN 14211 is fully satisfied.

Criterion satisfied? yes

6.6 Detailed presentation of test results

Table 14 and Table 15 present the individual results of the averaging test:

Table 14: Individual results of the averaging test for NO

		device 1	device 2
	time	[nmol/mol]	[nmol/mol]
average constant concentration $C_{av,c}$	07:15:00	590.5	588.1
	till		
	07:34:00		
average variable concentration $C_{av,c}$	07:35:00	291.2	279.4
	till		
	07:54:00		

		device 1	device 2
	time	[nmol/mol]	[nmol/mol]
average constant concentration $C_{av,c}$	08:05:00	592.2	590.4
	till		
	08:24:00		
average variable concentration $C_{av,c}$	08:25:00	302.1	290.1
	till		
	08:44:00		

		device 1	device 2
	time	[nmol/mol]	[nmol/mol]
average constant concentration $C_{av,c}$	08:56:00	594.4	592.7
	till		
	09:15:00		
average variable concentration $C_{av,c}$	09:16:00	290.7	282.3
	till		
	09:35:00		

Table 15: Individual results of the averaging test for NO_2

		device 1	device 2
	time	[nmol/mol]	[nmol/mol]
average constant concentration $C_{av,c}$	07:15:00	201.2	198.6
	till		
	07:34:00		
average variable concentration $C_{av,c}$	07:35:00	198.6	196.3
	till		
	07:54:00		

		device 1	device 2
	time	[nmol/mol]	[nmol/mol]
average constant concentration $C_{av,c}$	08:05:00	203.4	200.4
	till		
	08:24:00		
average variable concentration $C_{av,c}$	08:25:00	198.2	195.1
	till		
	08:44:00		

		device 1	device 2
	time	[nmol/mol]	[nmol/mol]
average constant concentration $C_{av,c}$	08:56:00	201.6	198.7
	till		
	09:15:00		
average variable concentration $C_{av,c}$	09:16:00	197.9	192.4
	till		
	09:35:00		

6.1 7.4.13 Difference between sample and calibration port

If a measuring system, standardly or optionally, possesses a test gas inlet separated from the sample gas inlet, this configuration shall be tested.
The difference between the measured values obtained by feeding gas at the sample gas and test gas inlet shall not exceed 1 %.

6.2 Equipment

Not applicable

6.3 Testing

The measuring system is not equipped with a test gas inlet separate from the sample gas inlet. Test gases have to be fed via the sample inlet.

6.4 Evaluation

This test criterion does not apply.

6.5 Assessment

This test criterion does not apply. The measuring system is not equipped with a test gas inlet separate from the sample gas inlet. Test gases have to be fed via the sample inlet.

Criterion satisfied? not applicable

6.6 Detailed presentation of test results

Not applicable in this instance.

6.1 7.4.14 Converter efficiency

In case of measuring systems with a converter, the converter efficiency shall be at least 98 % in the laboratory test.

6.2 Equipment

Not applicable

6.3 Testing

Determination and evaluation of the converter efficiency in the laboratory corresponds exactly to determining the converter efficiency in accordance with standard EN 14211 (2012). The reader is therefore referred to chapter 7.1 8.4.14 Converter efficiency.

The Model 405 nm measuring system does not use the EU reference method chemiluminescence as its measuring principle. This is why the measuring system does not have a standard NO-NO_2 converter. The Model 405 nm monitor directly analyses NO_2 in the UV range. NO is determined by oxidising sample air with ozone at alterating cycles. The difference between both measurements is output as the NO value. Even though the measuring system does not have a converter, the test was performed as described above in order to demonstrate that NO and NO_2 measurements are equivalent to the standard reference method.

6.4 Evaluation

See chapter 7.1 8.4.14 Converter efficiency

6.5 Assessment

See chapter 7.1 8.4.14 Converter efficiency

Criterion satisfied? yes

6.6 Detailed presentation of test results

Not applicable in this instance.

6.1 7.4.15 Residence time in the analyser

If the residence time has influence on the output signal, like for NO_X and ozone measuring systems, it is necessary to calculate the residence time from the volume flow and the volume of the gas lines and other relevant components of the measuring system and the particle filter casing.

In the case of NO_X and O_3 measurements, the residence time shall not exceed 3 s.

6.2 Equipment

Not applicable

6.3 Testing

Performing and evaluating the averaging effect corresponds exactly to determining the averaging test in accordance with standard EN 14211 (2012). This is why we refer to Chapter 7.1 8.4.14 Residence time in the analyser.

6.4 Evaluation

See chapter 7.1 8.4.14 Residence time in the analyser

6.5 Assessment

See chapter 7.1 8.4.14

Criterion satisfied? yes

6.6 Detailed presentation of test results

Not applicable in this instance.

6.1 7.5 Requirements on performance characteristics for testing in the field

6.1 7.5.1 General requirements

The performance characteristics which shall be determined during testing in the field and their related performance criteria for measured components according to 39. BImSchV are given in Table A1 of VDI 4202-1 (2018).
The certification range for other components is to be defined. Performance criteria are to be defined by drawing from Table A1 of VDI 4202-1 (2018) These definitions shall be cleared with the relevant body before testing.
The determination of the performance characteristics shall be done according to the procedures de-scribed in Section 8.5 of VDI 4202-1 (2018).

6.2 Equipment

Not required for this performance criterion

6.3 Testing

Tests were performed using the performance characteristics specified in VDI standard 4202, part 1 (2018) and standard EN 14211 (2012).

6.4 Evaluation

Not applicable.

6.5 Assessment

Tests were performed using the performance characteristics specified in VDI standard 4202, part 1 (2018) and standard EN 14211 (2012)

Criterion satisfied? yes

6.6 Detailed presentation of test results

Not applicable.

6.1 7.5.2 Location for the field test

The monitoring station for the field test is to be chosen according to the requirements of 39. BImSchV such that the expected concentrations of the measured components to be measured correspond to the designated task. The equipment of the monitoring station shall allow the implementation of the field test and shall fulfil all requirements considered to be necessary during measurement planning.

6.2 Equipment

Not required for this performance criterion

6.3 Testing

The field test location was selected in compliance with the 39th BImSchV.

6.4 Evaluation

The field test location was selected in compliance with the 39th BImSchV. The measuring station for the field test was located at a car park on the premises of TÜV Rheinland.

6.5 Assessment

The field test location was selected in compliance with the 39th BImSchV.

Criterion satisfied? yes

6.6 Detailed presentation of test results

Not applicable.

6.1 7.5.3 Test requirements

The measuring systems shall be installed in the monitoring station and, after connecting to the existing or separate sampling system, activated properly.
The adjustments of the measuring system shall meet the specifications of the manufacturer. All adjustments are to be documented in the test report.
The measuring systems shall be maintained during the field test, following the manufacturer's specifications, and shall be checked with suitable test gases regularly.
If the measuring system contains auto-scale or self-correction functions and they are treated as "normal operating conditions", these functions shall be turned on during the field test. Values of the self-correction shall be available to the test laboratory. The values of the auto-zero and auto-drift corrections for the inspection interval (long-term drift) are subject to the same restrictions as given in the performance characteristics.

6.2 Equipment

Not required for this performance criterion

6.3 Testing

For the purpose of field testing, the measuring system was mounted in a measuring station and connected to the existing sampling system. The measuring system was then commissioned following the manufacturer's instructions in the manual.

Neither self-correction nor auto-zero functions were activated during the field test.

6.4 Evaluation

During the field test, the measuring system was operated and serviced according to the manufacturer's instructions. Neither self-correction nor auto-zero functions were activated.

6.5 Assessment

During the field test, the measuring system was operated and serviced according to the manufacturer's instructions.

Criterion satisfied? yes

6.6 Detailed presentation of test results

Not applicable.

6.1 7.5.4 Long-term drift

The long-term drift at zero point shall not exceed 5.0 nmol/mol.
The long-term drift at reference point shall not exceed 5 % of the upper limit of the certification range.

6.2 Equipment

Not applicable

6.3 Testing

Determination and evaluation of the long-term drift corresponds exactly to determining the long term drift in accordance with standard EN 14211 (2012). The reader is therefore referred to chapter 7.1 8.5.4 Long-term drift.

6.4 Evaluation

See chapter 7.1 8.5.4 Long-term drift.

6.5 Assessment

See chapter 7.1 8.5.4 Long-term drift.

Criterion satisfied? yes

6.6 Detailed presentation of test results

Not applicable in this instance.

6.1 7.5.5 Reproducibility standard deviation under field conditions

The standard deviation from paired measurements under field conditions shall be determined with two identical measuring systems by paired measurements in the field test.
The standard deviation under field conditions shall not exceed 5% of the mean value over a period of three months.

6.2 Equipment

Not applicable

6.3 Testing

Performing and evaluating the standard deviation from paired measurements corresponds exactly to determining the reproducibility standard deviation in accordance with standard EN 14211 (2012). The reader is therefore referred to chapter 7.1 8.5.5 Reproducibility standard deviation for NO_2 under field conditions.

6.4 Evaluation

See chapter 7.1 8.5.5 Reproducibility standard deviation for NO_2 under field conditions

6.5 Assessment

See chapter 7.1 8.5.5 Reproducibility standard deviation for NO_2 under field conditions
Criterion satisfied? yes

6.6 Detailed presentation of test results

Not applicable in this instance.

6.1 7.5.6 Inspection interval

The inspection interval of the measuring system shall be determined during the field test and specified. The maintenance interval should be three months, if possible, but at least two weeks.

6.2 Equipment

Not required for this performance criterion

6.3 Testing

Performing and evaluating the inspection interval corresponds exactly to determining the period of unattended operation in accordance with standard EN 14211 (2012). The reader is therefore referred to chapter 7.1 8.5.6 Inspection interval.

6.4 Evaluation

See chapter 7.1 8.5.6 Inspection interval.

6.5 Assessment

See chapter 7.1 8.5.6 Inspection interval.

Criterion satisfied? yes

6.6 Detailed presentation of test results

Not applicable in this instance.

6.1 7.5.7 Availability

The availability of the measuring system shall be determined during the field test and shall be at least 95%.

6.2 Equipment

Not applicable

6.3 Testing

Determination and evaluation of the availability corresponds exactly to determining the period of availability of the analyser in accordance with standard EN 14211 (2012). This is why we refer to Chapter 7.1 8.5.7 Period of availability of the analyser.

6.4 Evaluation

See Chapter 7.1 8.5.7 Period of availability of the analyser

6.5 Assessment

See Chapter 7.1 8.5.7 Period of availability of the analyser

Criterion satisfied? yes

6.6 Detailed presentation of test results

Not applicable in this instance.

6.1 7.5.8 Converter efficiency

At the end of the field test, the converter efficiency shall be at least 95 %.

6.2 Equipment

Test samples, ozonator, NO test gas

6.3 Testing

VDI 4202-1:2018 additionally requires the converter efficiency to tested at the end of the field test. This test was performed following the procedures of EN 14211 for converter efficiency in the laboratory test.

The converter efficiency is determined by measurements with calculated amounts of NO_2. This can be achieved by means of gas-phase titration of NO to NO_2 with ozone.

The test shall be performed at two concentration levels: at about 50% and about 95% of the maximum of the certification range of NO_2.

The NO_x measuring system shall be calibrated applying an NO concentration of about 70% to 80% of the maximum certification range for NO to the NO and NO_x channels. Both channels need to be adjusted to display the same value. The values shall be recorded.

A known NO concentration at 50% of the NO certification range is applied to the measuring system until a stable signal is obtained This stable period shall be at least as long as four response times. Four individual readings each are performed at the NO and the NO_x channel. Then, NO is brought to react with O_3 to produce NO_2. This mixture containing a constant NO_x concentration is applied to the measuring system until the output signal has stabilised. This stable period shall be at least four response times of the measuring system under test; the NO concentration after gas-phase titration shall be between 10% and 20% of the original NO concentration. Then, four individual readings each are performed at the NO and the NO_x channel. Then, the O_3 supply is cut and only NO is applied to the measuring system until the output signal has stabilised again. This stable period shall be at least as long as four response times of the measuring system. After that the average of the four individual measurements at the NO and the NO_x channel is calculated.

The converter efficiency is calculated as follows:

$$E_{conv} = \left(1 - \frac{(NO_x)_i - (NO_x)_f}{(NO)_i - (NO)_f} \right) \times 100\%$$

Where:

E_{conv}	is the converter efficiency in %;
$(NO_x)_i$	is the average of the four individual measurements at the NOx channel at the initial NOx concentration;
$(NO_x)_f$	is the average of the four individual measurements at the NO_x channel at the resulting NO_x concentration after applying O_3;
$(NO)_i$	is the average of the four individual measurements at the NO channel at the initial NO concentration;
$(NO)_f$	is the average of the four individual measurements at the NO channel at the resulting NO concentration after applying O_3;

The lowest value of the two converter efficiencies shall be reported.

The Model 405 nm measuring system does not use the EU reference method chemiluminescence as its measuring principle. This is why the measuring system does not have a standard NO-NO_2 converter. The Model 405 nm monitor directly analyses NO_2 in the UV range. NO is determined by oxidising sample air with ozone at alterating cycles. The difference between both measurements is output as the NO value. Even though the measuring system does not have a converter, the test was performed as described above in order to demonstrate that NO and NO_2 measurements are equivalent to the standard reference method.

The test was performed in compliance with the requirements specified in EN 14211. When applying test gas two NO_2 concentrations in the range of 50% to 95% of the certification range for NO_2 were adjusted by means of gas-phase titration.

The converter efficiency was determined at the end of the field test.

6.4 Evaluation

During the test, the following converter efficiencies were determined for the two Model 405 nm measuring systems. The lowest value of the two NO_2 concentration is reported below.

	requirement	device 1		device 2	
converter efficiency E_c [%]	≥ 98%	99.8	✓	99.7	✓

6.5 Assessment

The performance criterion specified by standard VDI 4202-1 (2018) is fully satisfied.

Criterion satisfied? yes

6.6 Detailed presentation of test results

Table 16 presents the individual values.

Table 16: Individual results for the converter efficiency

				device 1		device 2	
	time	O_3 [nmol/mol]	NO_2 [nmol/mol]	NO [nmol/mol]	NO_x [nmol/mol]	NO [nmol/mol]	NO_x [nmol/mol]
	14:10:00	start					
O_3=0, NO=50%	14:22:00	0.0	0.5	481.2	482.9	482.6	483.6
	14:26:00	0.0	0.6	482.3	482.9	482.9	483.1
	14:30:00	0.0	0.5	482.0	482.4	483.6	483.4
	14:46:00	0.0	0.4	481.6	482.6	482.9	483.2
average		0.0	0.5	481.8	482.7	483.0	483.3
NO_2= 50% 130.75	15:02:00	131.0	132.5	349.8	483.6	350.0	484.1
	15:06:00	131.0	133.6	350.2	483.4	350.0	484.2
	15:10:00	131.0	133.1	350.6	483.6	350.0	483.7
	15:26:00	131.0	132.4	350.2	483.5	350.0	484.2
average		131.0	132.9	350.2	483.5	350.0	484.1
O_3=0, NO=50%	16:12:00	0.0	0.5	481.0	481.6	483.6	484.5
	16:16:00	0.0	0.4	482.6	482.9	483.1	484.0
	16:20:00	0.0	0.1	482.1	481.9	483.1	483.9
	16:24:00	0.0	0.2	481.9	482.0	482.4	482.6
average		0.0	0.3	481.9	482.1	483.1	483.8
NO_2= 95% 248.43	16:40:00	250.0	247.9	234.9	482.8	234.5	483.6
	16:44:00	250.0	247.1	233.1	480.2	235.0	482.1
	16:48:00	250.0	247.6	233.4	481.0	235.6	483.2
	16:52:00	250.0	248.6	233.4	482.0	234.8	483.4
average		250.0	247.8	233.7	481.5	235.0	483.1
O_3=0, NO=50%	17:08:00	0.0	0.6	482.6	483.1	482.4	484.0

6.1 7.6 Type approval and calculation of the measurement uncertainty

The type approval of the measuring system re-quires the following:

1) The value of each individual performance characteristic tested in the laboratory shall fulfil the criterion stated in Table C1 of VDI 4202-1 (2018).

2) The expanded uncertainty calculated from the standard uncertainties due to the values of the specific performance characteristics obtained in the laboratory tests shall fulfil the criterion as stated Table C1 of VDI 4202-1 (2018). *This criterion is the maximum uncertainty of individual measurements for continuous measurements at the 1-hour limit value. The relevant specific performance characteristics and the calculation procedure are given in Annex F of standard VDI 4202-1 (2018).*

3) The value of each individual performance characteristic tested in the laboratory shall fulfil the criterion stated in Table A1 of VDI 4202-1 (2018).

4) The expanded uncertainty calculated from the standard uncertainties due to the values of the specific performance characteristics obtained in the laboratory and field tests shall fulfil the criterion as stated Table C1 of VDI 4202-1 (2018). This criterion is the maximum uncertainty of individual measurements for continuous measurements at the 1-hour limit value. The relevant specific performance characteristics and the calculation procedure are given in Annex F.

6.2 Equipment

Not applicable

6.3 Testing

Uncertainty calculation was performed in line with standard EN 14211 (2012) and is presented in 7.1 8.6 Calculation of the total uncertainty in accordance with standard EN 14211 (2012) according to Annex E of EN 14211 (2012).

6.4 Evaluation

Uncertainty calculation was performed in line with standard EN 14211 (2012) and is presented in 7.1 8.6 Calculation of the total uncertainty in accordance with standard EN 14211 (2012) according to Annex E of EN 14211 (2012).

6.5 Assessment

Uncertainty calculation war performed in line with standard EN 14211 (2012) and is presented in 7.1 8.6 Calculation of the total uncertainty in accordance with standard EN 14211 (2012) according to Annex E of EN 14211 (2012)

Criterion satisfied? yes

6.6 Detailed presentation of test results

Not applicable in this instance.

6. Test Results in accordance with Standard EN 14211 (2012)

7.1 8.4.3 Response time

Rise and fall response time ≤ 180 s each. Difference between rise and fall response time ≤ 10 s.

7.2 Testing

The determination of the response time shall be carried out by applying to the analyser a step function in the concentration from less than 20 % to about 80 % of the maximum of the certification range of NO and vice versa.

The change from zero gas to span gas and vice versa needs to be made almost instantaneously, with the use of a suitable valve. The valve outlet shall be mounted direct to the inlet of the analyser, and both zero gas and span gas shall have the same amount of gas in excess, which is vented by the use of a tee. The gas flows of both zero gas and span gas shall be chosen in such a way that the dead time in the valve and tee can be neglected compared to the lag time of the analyser system. The step change is made by switching the valve from zero gas to span gas. This event needs to be timed and is the start (t = 0) of the (rise) lag time fort the dead time (rise) as shown in Figure 7. When the reading shows 98% of the applied concentration, the span gas can be changed to zero gas again; this event is the start (t = 0) of the (fall) lag time. When the reading shows 2% of the applied concentration, the whole cycle as shown in Figure 7 is complete.

The elapsed time (response time) between the start of the step change and reaching 90% of the analyser final stable reading of the applied concentration shall be measured. The whole cycle shall be repeated four times. The average of the four response times (rise) and the average of the four response times (fall) shall be calculated.

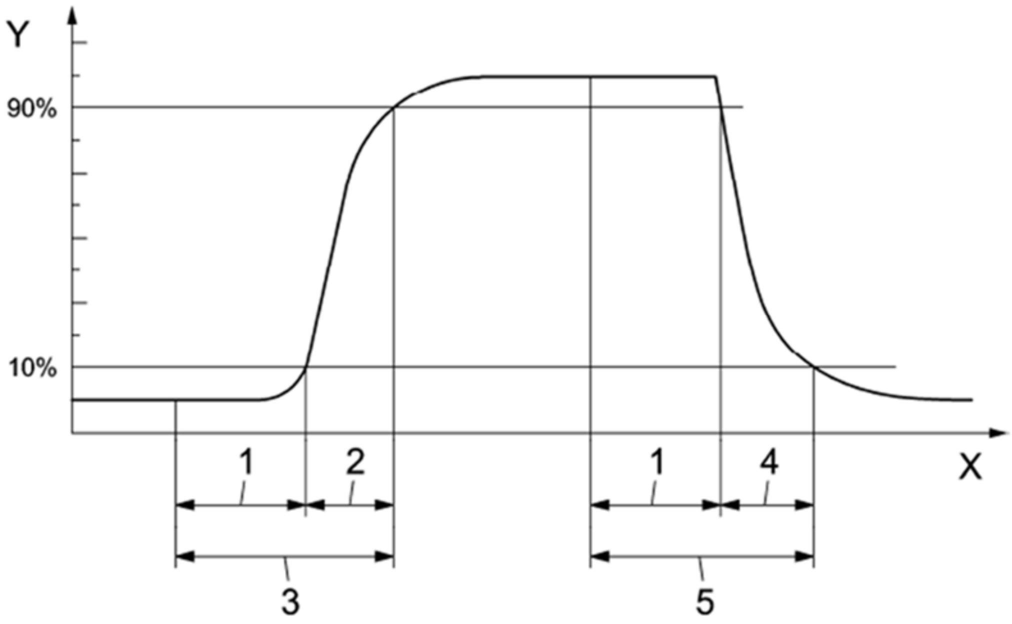
The test shall then be repeated with NO_2 at levels from less than 20 % to about 80 % of the maximum of the certification range of NO_2 and vice versa.

The difference in response times shall be calculated according to: Where:

$$t_d = \bar{t}_r - \bar{t}_f$$

Where T_d is the difference between response time (rise) and response time (fall), in s;
t_r is the response time (rise) (average of the four response times - rise), in s;
t_f is the response time (fall) (average of the four response times - fall), in s.

t_r, t_f and t_d shall comply with the performance criteria indicated above.



Key

Y	analyser response
X	time
1	lag time
2	rise time
3	response time (rise)
4	fall time
5	response time (fall)

Figure 7: Diagram illustrating the response time

7.3 Testing

The test was performed in line with the requirements of EN 14211 mentioned before. An external data logger was used to record data.

7.4 Evaluation

Table 17: Response times of the two Model 405 nm measuring systems for NO

	requirement	device 1		device 2	
average rise t_r [s]	≤ 180 s	28	✓	27	✓
average fall t_f [s]	≤ 180 s	28	✓	28	✓
difference t_d [s]	≤ 10 s	0.0	✓	-1.0	✓

For NO, system 1, the average t_r was 28 s, the average t_f was 28 s and t_d 0 s.
For NO, system 2, the average t_r was 27 s, the average t_f was 28 s and t_d -1 s.

Table 18: Response times of the two Model 405 nm measuring systems for NO_2

	requirement	device 1		device 2	
average rise t_r [s]	≤ 180 s	34.5	✓	35.5	✓
average fall t_f [s]	≤ 180 s	36	✓	37.5	✓
difference t_d [s]	≤ 10 s	-1.5	✓	-2.0	✓

For NO_2, system 1, the average t_r was 34.5, the average t_f was 36 and t_d -1.5 s.
For NO_2, system 2, the average t_r was 35.5, the average t_f was 37.5 and t_d -2 s.

7.5 Assessment

The values determined remained considerably below the maximum permissible response time of 180 s at all times. The maximum response time determined for instrument 1 was 28 s for NO and 36 s for NO_2. For instrument 2 it was determined at 28 s for NO and 37.5 s for NO_2.

Criterion satisfied? yes

7.6 Detailed presentation of test results

Table 19: Individual results of the response time for NO

		device 1					
	80%	rise			fall		
measuring range	768.00	0.0 0.00	0.9 691.20	1.0 768.00	1.0 768.00	0.1 76.80	0.0 0.00
cycle 1	t = 0	10:30:00	10:30:28	10:31:00	10:37:00	10:37:28	10:38:00
	delta t		00:00:28			00:00:28	
	delta t [s]		28			28	
cycle 2	t = 0	10:45:00	10:45:28	10:46:00	10:51:00	10:51:28	10:52:00
	delta t		00:00:28			00:00:28	
	delta t [s]		28			28	
cycle 3	t = 0	10:59:00	10:59:28	11:00:00	11:05:00	11:05:28	11:06:00
	delta t		00:00:28			00:00:28	
	delta t [s]		28			28	
cycle 4	t = 0	11:13:00	11:13:28	11:14:00	11:19:00	11:19:28	11:20:00
	delta t		00:00:28			00:00:28	
	delta t [s]		28			28	

		device 2					
	80%	rise			fall		
measuring range	768.00	0.0 0.00	0.9 691.20	1.0 768.00	1.0 768.00	0.1 76.80	0.0 0.00
cycle 1	t = 0	10:30:00	10:30:26	10:31:00	10:37:00	10:37:28	10:38:00
	delta t		00:00:26			00:00:28	
	delta t [s]		26			28	
cycle 2	t = 0	10:45:00	10:45:28	10:46:00	10:51:00	10:51:28	10:52:00
	delta t		00:00:28			00:00:28	
	delta t [s]		28			28	
cycle 3	t = 0	10:59:00	10:59:26	11:00:00	11:05:00	11:05:28	11:06:00
	delta t		00:00:26			00:00:28	
	delta t [s]		26			28	
cycle 4	t = 0	11:13:00	11:13:28	11:14:00	11:19:00	11:19:28	11:20:00
	delta t		00:00:28			00:00:28	
	delta t [s]		28			28	

Table 20: Individual results of the response time for NO_2

		device 1					
	80%	rise			fall		
measuring range	209.21	0.0 0.00	0.9 188.28	1.0 209.21	1.0 209.21	0.1 20.92	0.0 0.00
cycle 1	t = 0	10:04:00	10:04:35	10:05:00	10:11:00	10:11:36	10:12:00
	delta t		00:00:35			00:00:36	
	delta t [s]		35			36	
cycle 2	t = 0	10:19:00	10:19:34	10:20:00	10:26:00	10:26:36	10:27:00
	delta t		00:00:34			00:00:36	
	delta t [s]		34			36	
cycle 3	t = 0	10:33:00	10:33:34	10:34:00	10:40:00	10:40:36	10:41:00
	delta t		00:00:34			00:00:36	
	delta t [s]		34			36	
cycle 4	t = 0	10:47:00	10:47:35	10:48:00	10:54:00	10:54:36	10:55:00
	delta t		00:00:35			00:00:36	
	delta t [s]		35			36	

		device 2					
	80%	rise			fall		
measuring range	209.21	0.0 0.00	0.9 188.28	1.0 209.21	1.0 209.21	0.1 20.92	0.0 0.00
cycle 1	t = 0	10:04:00	10:04:36	10:04:00	10:11:00	10:11:38	10:12:00
	delta t		00:00:36			00:00:38	
	delta t [s]		36			38	
cycle 2	t = 0	10:19:00	10:19:34	10:20:00	10:26:00	10:26:38	10:27:00
	delta t		00:00:34			00:00:38	
	delta t [s]		34			38	
cycle 3	t = 0	10:33:00	10:33:36	10:34:00	10:40:00	10:40:36	10:41:00
	delta t		00:00:36			00:00:36	
	delta t [s]		36			36	
cycle 4	t = 0	10:47:00	10:47:36	10:48:00	10:54:00	10:54:38	10:55:00
	delta t		00:00:36			00:00:38	
	delta t [s]		36			38	

7.1 8.4.4 Short-term drift

Short-term drift at zero shall not exceed 2.0 nmol/mol/12 h.
The short-term drift at reference level shall not exceed 6.0 nmol/mol/12 h.

7.2 Testing

After the required stabilisation period, the analyser shall be adjusted at zero and span level (around 70% to 80% of the maximum of the certification range). Wait the time equivalent to one independent reading and then record 20 individual measurements, first at zero and then at span concentration. From these 20 measurements, the average is calculated for zero and span level.

The analyser shall be kept running under the laboratory conditions. After a period of 12 h, zero and span gas is fed to the analyser. Wait the time equivalent to one independent reading and then record 20 individual measurements, first at zero and then at span concentration. The averages for zero and span level shall be calculated.

The short-term drift at zero and span level shall be calculated as follows:

$$D_{S,Z} = (C_{Z,2} - C_{Z,1})$$

Where:

$D_{S,Z}$ is the 12-hour drift at zero;

$C_{Z,1}$ is the average concentration of the measurements at zero at the beginning of the drift period;

$C_{Z,2}$ is the average concentration of the measurements at zero at the end of the drift period;

$D_{S,Z}$ shall comply with the performance criterion indicated above.

$$D_{S,S} = (C_{S,2} - C_{S,1}) - D_{S,Z}$$

Where:

$D_{S,S}$ is the 12-hour drift at span;

$C_{S,1}$ is the average concentration of the measurements at span level at the beginning of the drift period;

$C_{S,2}$ is the average concentration of the measurements at span level at the end of the drift period.

$D_{S,S}$ shall comply with the performance criterion indicated above.

7.3 Testing

The test was performed in line with the requirements of EN 14211 mentioned before. In compliance with the standard, the test has to be performed with the component NO. Pursuant to EN 14211, the test shall be performed at a concentration level of 70% to 80% of the certification range for NO.

In addition, the test was performed for NO_2 at a concentration level of 70% to 80% of the certification range for NO_2.

7.4 Evaluation

Table 21 and Table 22 indicate the results of the short-term drift test.

Table 21: Results of the short-term drift test for NO

	requirements	device 1		device 2	
averange at zero at the beginning [nmol/mol]	-	0.87		-0.92	
averange at zero at the end [nmol/mol]	-	0.34		-1.43	
averange at span at the beginning [nmol/mol]	-	719.20		718.20	
averange at span at the end [nmol/mol]	-	716.98		717.50	
12-hour drift at zero $D_{s,z}$ [nmol/mol]	≤ 2,0	-0.53	✓	-0.51	✓
12-hour drift at span $D_{s,s}$ [nmol/mol]	≤ 6,0	-1.69	✓	-0.20	✓

Table 22: Results of the short-term drift test for NO_2

	requirements	device 1		device 2	
averange at zero at the beginning [nmol/mol]	-	-0.73		-1.09	
averange at zero at the end [nmol/mol]	-	-0.56		-0.44	
averange at span at the beginning [nmol/mol]	-	208.83		202.72	
averange at span at the end [nmol/mol]	-	206.92		204.35	
12-hour drift at zero $D_{s,z}$ [nmol/mol]	≤ 2,0	0.17	✓	0.65	✓
12-hour drift at span $D_{s,s}$ [nmol/mol]	≤ 6,0	-2.08	✓	0.98	✓

7.5 Assessment

For NO, the value for the short-term drift at zero point was -0.53 nmol/mol for instrument 1; for instrument 2, it was -0.51 nmol/mol.

For NO, the value for the short-term drift at span point was -1.69 nmol/mol for instrument 1; for instrument 2, it was -0.20 nmol/mol.

For NO_2, the value for the short-term drift at zero point was 0.17 nmol/mol for instrument 1; for instrument 2, it was 0.65 nmol/mol.

For NO_2, the value for the short-term drift at span point was -2.08 nmol/mol for instrument 1; for instrument 2, it was 0.98 nmol/mol.

Criterion satisfied? yes

7.6 Detailed presentation of test results

Table 23 to Table 26 present the individual test results.

Table 23: Individual results for the short-term drift 1 Test gas feeding for NO

at beginning		
zero level		
	device 1	device 2
time	[nmol/mol]	[nmol/mol]
13:29:00	0.9	-1.4
13:30:00	0.5	-0.9
13:31:00	1.2	-1.4
13:32:00	0.6	-0.8
13:33:00	0.2	0.0
13:34:00	0.5	-0.1
13:35:00	-0.2	-0.7
13:36:00	-0.6	-1.3
13:37:00	-0.3	-1.0
13:38:00	0.3	-1.5
13:39:00	1.8	-1.4
13:40:00	1.0	-0.7
13:41:00	1.2	-0.6
13:42:00	1.6	-0.7
13:43:00	1.4	-1.5
13:44:00	1.5	-1.5
13:45:00	1.4	-1.6
13:46:00	1.3	-1.6
13:47:00	1.3	0.0
13:48:00	1.7	0.4
average	**0.9**	**-0.9**

at beginning		
span level		
	device 1	device 2
time	[nmol/mol]	[nmol/mol]
13:54:00	723.3	718.1
13:55:00	722.3	717.8
13:56:00	719.7	717.1
13:57:00	719.3	717.3
13:58:00	718.7	717.8
13:59:00	718.4	718.2
14:00:00	718.5	718.0
14:01:00	718.3	718.5
14:02:00	718.3	718.4
14:03:00	717.6	718.5
14:04:00	718.0	717.8
14:05:00	718.0	718.5
14:06:00	718.8	718.1
14:07:00	718.4	719.3
14:08:00	718.9	718.9
14:09:00	718.7	719.5
14:10:00	719.2	718.6
14:11:00	719.9	717.7
14:12:00	720.0	718.0
14:13:00	719.6	717.9
average	**719.2**	**718.2**

Table 24: Individual results for the short-term drift 2 Test gas feeding for NO

after 12h		
zero level		
	device 1	device 2
time	[nmol/mol]	[nmol/mol]
01:29:00	-0.2	-1.5
01:30:00	-0.8	-1.4
01:31:00	-1.0	-1.8
01:32:00	-0.9	-1.5
01:33:00	-0.5	-1.8
01:34:00	-0.6	-1.4
01:35:00	-0.7	-1.9
01:36:00	-0.7	-1.5
01:37:00	-0.5	-1.4
01:38:00	0.9	-1.8
01:39:00	1.6	-1.9
01:40:00	1.6	-1.4
01:41:00	1.1	-1.1
01:42:00	0.5	-1.7
01:43:00	0.6	-2.0
01:44:00	1.1	-1.6
01:45:00	1.1	-0.5
01:46:00	1.3	-0.7
01:47:00	1.4	-0.6
01:48:00	1.4	-1.0
average	**0.3**	**-1.4**

after 12h		
span level		
	device 1	device 2
time	[nmol/mol]	[nmol/mol]
01:54:00	721.9	716.9
01:55:00	718.5	715.5
01:56:00	717.1	715.1
01:57:00	716.1	714.7
01:58:00	715.5	714.4
01:59:00	715.4	715.0
02:00:00	715.2	715.4
02:01:00	715.1	716.0
02:02:00	715.4	718.8
02:03:00	715.7	718.7
02:04:00	714.9	718.5
02:05:00	716.0	718.4
02:06:00	714.3	718.4
02:07:00	715.2	719.2
02:08:00	716.2	719.2
02:09:00	718.8	719.6
02:10:00	719.3	718.4
02:11:00	719.9	719.8
02:12:00	719.8	718.5
02:13:00	719.2	719.4
average	**717.0**	**717.5**

Table 25: Individual results for the short-term drift 1 Test gas feeding for NO_2

at beginning		
zero level		
	device 1	device 2
time	[nmol/mol]	[nmol/mol]
13:29:00	-1.3	-1.5
13:30:00	-1.2	-1.5
13:31:00	-0.7	-1.3
13:32:00	-0.4	-1.5
13:33:00	-0.4	-1.5
13:34:00	-0.9	-1.0
13:35:00	-0.4	-1.3
13:36:00	0.0	-1.1
13:37:00	-0.7	-1.1
13:38:00	-0.6	-1.1
13:39:00	-0.9	-0.5
13:40:00	-1.1	-0.6
13:41:00	-1.4	-0.6
13:42:00	-0.7	-1.2
13:43:00	-0.6	-1.3
13:44:00	-0.7	-1.6
13:45:00	-1.0	-1.1
13:46:00	-0.7	-1.0
13:47:00	-0.4	-0.4
13:48:00	-0.4	-0.5
average	**-0.7**	**-1.1**

at beginning		
span level		
	device 1	device 2
time	[nmol/mol]	[nmol/mol]
13:54:02	204.6	203.6
13:55:02	207.9	200.5
13:56:02	204.7	204.3
13:57:02	208.4	202.5
13:58:02	210.6	202.6
13:59:02	210.9	202.4
14:00:02	210.8	202.0
14:01:02	210.7	202.6
14:02:02	210.2	202.1
14:03:02	210.3	202.0
14:04:02	210.6	202.9
14:05:02	210.5	202.0
14:06:02	210.3	202.7
14:07:02	209.8	204.4
14:08:02	209.4	204.3
14:09:02	208.7	204.0
14:10:02	208.0	203.5
14:11:02	207.3	202.8
14:12:02	206.6	201.6
14:13:02	206.2	201.6
average	**208.8**	**202.7**

Table 26: Individual results for the short-term drift 2 Test gas feeding for NO_2

after 12h		
zero level		
	device 1	device 2
time	[nmol/mol]	[nmol/mol]
01:29:00	0.7	-0.4
01:30:00	0.8	-0.1
01:31:00	0.0	-0.1
01:32:00	-0.3	0.5
01:33:00	-0.9	0.1
01:34:00	-0.9	-0.1
01:35:00	-0.5	-0.2
01:36:00	-0.3	0.4
01:37:00	-0.1	0.1
01:38:00	0.2	0.1
01:39:00	-0.1	-0.2
01:40:00	-0.4	-1.1
01:41:00	-1.5	-0.8
01:42:00	-1.5	-0.6
01:43:00	-1.4	0.5
01:44:00	-1.2	-0.1
01:45:00	-1.1	-1.2
01:46:00	-0.9	-2.0
01:47:00	-0.8	-2.2
01:48:00	-1.0	-1.3
average	**-0.6**	**-0.4**

after 12h		
span level		
	device 1	device 2
time	[nmol/mol]	[nmol/mol]
01:54:00	209.0	201.8
01:55:00	208.5	201.8
01:56:00	205.1	203.9
01:57:00	204.6	204.7
01:58:00	205.3	202.6
01:59:00	204.3	205.1
02:00:00	207.9	204.6
02:01:00	207.5	208.8
02:02:00	207.8	205.8
02:03:00	204.9	203.9
02:04:00	207.5	205.7
02:05:00	208.5	206.1
02:06:00	208.4	206.3
02:07:00	207.5	202.0
02:08:00	207.4	202.5
02:09:00	207.0	202.7
02:10:00	206.7	205.8
02:11:00	206.5	204.5
02:12:00	207.1	203.9
02:13:00	206.8	204.5
average	**206.9**	**204.4**

7.1 8.4.5 Repeatability standard deviation

The performance criteria are as follows: Repeatability standard deviation at zero shall not exceed 1.0 nmol/mol. At a sample gas concentration at the reference point it shall not exceed 3 nmol/mol.

7.2 Test procedure

After waiting the time equivalent of one independent reading, 20 individual measurements both at zero concentration and at an NO test concentration (c_t) of (500 ± 50) nmol/mol shall be performed.

From these measurements, the repeatability standard deviation (sr) at zero concentration and at concentration c_t shall be calculated according to:

$$s_r = \sqrt{\frac{\sum\left(x_i - \overline{x}\right)^2}{n-1}}$$

Where:

s_r the repeatability standard deviation;

x_i the ith measurement;

$\overline{x}$ is the average of the 20 measurements;

n is the number of measurements.

The repeatability standard deviation shall be calculated separately for both series of measurements (zero gas and concentration c_t).

s_r shall comply with the performance criterion indicated above, both at zero and at the test gas concentration c_t.of (500 ± 50) nmol/mol.

The detection limit, lower detection limit of the measuring system is calculated from the repeatability standard deviation and the slope of the calibration function determined in accordance with Chapter 8.4.6 according to the following equation:

$$l_{\text{det}} = 3{,}3 \cdot \frac{s_{r,z}}{B}$$

Where:

l_{det} is the detection limit, lower detection limit of the measuring system, in nmol/mol;

$s_{r,z}$ is the repeatability standard deviation at zero, in nmol/mol;

B is the slope of the calibration function according to Annex A based on the data from 8.4.6.

7.3 Testing

The test was performed in line with the requirements of EN 14211 mentioned before. In compliance with the standard, the test has to be performed with the component NO. Pursuant to EN 14211, the test shall be performed at a concentration level of 500 nmol/mol NO.

In addition, the test was also performed for NO_2 at the zero point and at a span concentration at the level of the 1h limit value for NO_2 (104 nmol/mol).

7.4 Evaluation

Table 28 and Table 30 presents the results for the repeatability standard deviation.

Table 27: Repeatability standard deviation at zero and reference point for NO

	requirement	device 1		device 2	
repeatability standard deviation $s_{r,z}$ at zero [nmol/mol]	≤ 1,0	0.67	✓	0.50	✓
repeatability standard deviation $s_{r,ct}$ at c_t [nmol/mol]	≤ 3,0	1.07	✓	1.03	✓
detection limit [nmol/mol]		2.22		1.65	

Table 28: Repeatability standard deviation at zero and reference point for NO_2

	requirement	device 1		device 2	
repeatability standard deviation $s_{r,z}$ at zero [nmol/mol]	≤ 1,0	0.35	✓	0.57	✓
repeatability standard deviation $s_{r,ct}$ at c_t [nmol/mol]	≤ 3,0	0.88	✓	0.78	✓
detection limit [nmol/mol]		1.17		1.89	

7.5 Assessment

For NO, the value for the repeatability standard deviation at zero point was 0.67 nmol/mol for instrument 1; for instrument 2 it was 0.50 nmol/mol. Repeatability standard deviation at reference point was 1.07 nmol/mol for instrument 1 and 1.03 nmol/mol for instrument 2.

For NO_2, the value for the repeatability standard deviation at zero point was 0.35 nmol/mol for instrument 1; for instrument 2 it was 0.57 nmol/mol. Repeatability standard deviation at reference point was 0.88 nmol/mol for instrument 1 and 0.78 nmol/mol for instrument 2.

Criterion satisfied? yes

7.6 Detailed presentation of test results

Table 29 and Table 30 list the results of individual measurements.

Table 29: Individual test results obtained for the repeatability standard deviation for NO

zero level		
	device 1	device 2
time	[nmol/mol]	[nmol/mol]
12:30:00	-0.2	-1.0
12:31:00	0.2	-0.5
12:32:00	0.2	-0.2
12:33:00	0.4	-1.1
12:34:00	0.2	-1.6
12:35:00	0.3	-1.7
12:36:00	0.3	-0.8
12:37:00	0.1	-0.7
12:38:00	0.3	-0.8
12:39:00	-0.1	-0.8
12:40:00	-0.9	-0.7
12:41:00	-0.9	-0.8
12:42:00	-0.7	-0.8
12:43:00	-1.0	-0.5
12:44:00	-0.5	-0.2
12:45:00	-0.6	-0.5
12:46:00	0.0	-1.3
12:47:00	0.5	-1.8
12:48:00	1.3	-1.8
12:49:00	1.5	-1.3
average	0.0	-0.9

c_t level		
	device 1	device 2
time	[nmol/mol]	[nmol/mol]
12:55:00	499.1	497.5
12:56:00	498.8	496.5
12:57:00	498.9	497.1
12:58:00	498.9	497.0
12:59:00	499.0	496.4
13:00:00	498.8	495.6
13:01:00	498.4	495.3
13:02:00	497.5	495.4
13:03:00	496.9	495.4
13:04:00	496.6	495.6
13:05:00	496.6	495.7
13:06:00	496.9	495.8
13:07:00	496.7	495.9
13:08:00	497.0	495.2
13:09:00	497.0	494.8
13:10:00	496.9	493.9
13:11:00	496.4	493.9
13:12:00	496.2	493.9
13:13:00	496.3	494.5
13:14:00	496.8	495.9
average	497.5	495.6

Table 30: Individual test results obtained for the repeatability standard deviation for NO_2

zero level		
	device 1	device 2
time	[nmol/mol]	[nmol/mol]
12:27:00	0.3	-1.3
12:28:00	0.3	-1.5
12:29:00	0.4	-1.0
12:30:00	0.8	-0.6
12:31:00	1.1	-0.4
12:32:00	1.4	-0.4
12:33:00	1.0	0.0
12:34:00	0.8	0.6
12:35:00	0.5	0.4
12:36:00	0.9	-0.5
12:37:00	1.1	-1.0
12:38:00	1.1	-1.4
12:39:00	1.3	-0.8
12:40:00	1.0	-0.7
12:41:00	1.3	-0.2
12:42:00	1.1	-0.4
12:43:00	1.1	-0.1
12:44:00	1.2	-0.9
12:45:00	1.4	-1.1
12:46:00	1.3	-0.9
average	1.0	-0.6

c_t level		
	device 1	device 2
time	[nmol/mol]	[nmol/mol]
12:52:00	105.3	105.1
12:53:00	105.8	106.8
12:54:00	104.2	106.7
12:55:00	104.0	106.7
12:56:00	106.0	106.9
12:57:00	107.6	106.7
12:58:00	107.3	108.5
12:59:00	106.0	108.9
13:00:00	106.5	107.8
13:01:00	106.5	107.8
13:02:00	106.4	107.0
13:03:00	106.4	107.8
13:04:00	106.6	107.5
13:05:00	106.6	107.5
13:06:00	106.0	107.4
13:07:00	106.5	107.4
13:08:00	106.8	107.2
13:09:00	106.5	107.7
13:10:00	106.5	107.6
13:11:00	106.9	107.2
average	106.2	107.3

7.1 8.4.6 Lack of fit of linearity of the calibration function

The deviation from the linearity of the calibration function at zero shall not exceed 5 nmol/mol. At concentrations above zero, it shall not exceed 4% of the measured value.

7.2 Test procedure

The lack of fit of linearity of the calibration function of the analyser shall be tested over the range of 0% to 95% of the maximum of the certification range of NO, using at least six concentrations (including the zero point). The analyser shall be adjusted at a concentration of about 90% of the maximum of the certification range. At each concentration (including zero) at least five individual measurements shall be performed.

The concentrations shall be applied in the following sequence: 80%, 40%, 0%, 60%, 20% and 95%. After each change in concentration, at least four response times shall be taken into account before the next measurement is performed.

The regression function and the deviations are calculated in accordance with Annex A of standard EN 14211. The deviations from the linear regression function shall comply with the performance criterion specified above.

Establishment of the regression line:

A linear regression function in the form of $Y_i = A + B * X_i$ is made through calculation of the following formula:

$$Y_i = a + B(X_i - X_z)$$

For the regression calculation, all measuring points (including zero) are taken into account. The total number of measuring points is equal to the number of concentration levels (at least six including zero) times the number of repetitions (at least five) at a particular concentration level.

The coefficient a is obtained from:

$$a = \sum Y_i / n$$

Where:

a is the average value of the Y-values;
Y_i is the individual Y-value;
N is the number of measuring points.

The coefficient B is obtained from:

$$B = \left(\sum Y_i (X_i - X_z)\right) / \sum (X_i - X_z)^2$$

Where:

X_z is the average of the x-values $\left(= \sum (X_i / n)\right)$
X_i is the individual x-value.

is the individual x-value. The function $Y_i = a + B (X_i – X_z)$is converted to $Y_i = A + B * X_i$ through the calculation of A:

$A = a – B * X_z$

The residuals of the averages of each calibration point (including the zero point) are calculated as follows.
The average of each calibration point (including the zero point) at one and the same concentration c is calculated according to:

$$(Y_a)_c = \sum (Y_i)_c / m$$

Where:

$(Y_a)_c$ is the average y-value at concentration level c;
$(Y_i)_c$ is the individual y-value at concentration level c;
M is the number of repetitions at one and the same concentration level c;

The residual of each average (r_c) at each concentration level is calculated according to:

$$r_c = (Y_a)_c - (A + B \times c)$$

Each residual to a value relative to its own concentration level c is expressed in % as:

$$r_{c,rel} = \frac{r_c}{c} \times 100\,\%$$

7.3 Testing

The test for the component NO was performed in line with the requirements of EN 14211 mentioned before.

In addition, the test for the component NO_2 was performed in the certification range 0-261 nmol/mol.

7.4 Evaluation

The following linear regressions were established:

Figure 8 to Figure 11 summarise the results of the group averaging tests.

Table 31: Deviation from the analytical function for NO

	requirements	device 1		device 2	
largest value of the relative residuals r_{max} [%]	≤ 4,0	0.66	✓	1.15	✓
residual at zero r_z [nmol/mol]	≤ 5,0	-0.06	✓	-0.70	✓

Table 32: Deviation from the analytical function for NO_2

	requirements	device 1		device 2	
largest value of the relative residuals r_{max} [%]	≤ 4,0	2.36	✓	3.29	✓
residual at zero r_z [nmol/mol]	≤ 5,0	1.50	✓	-0.24	✓

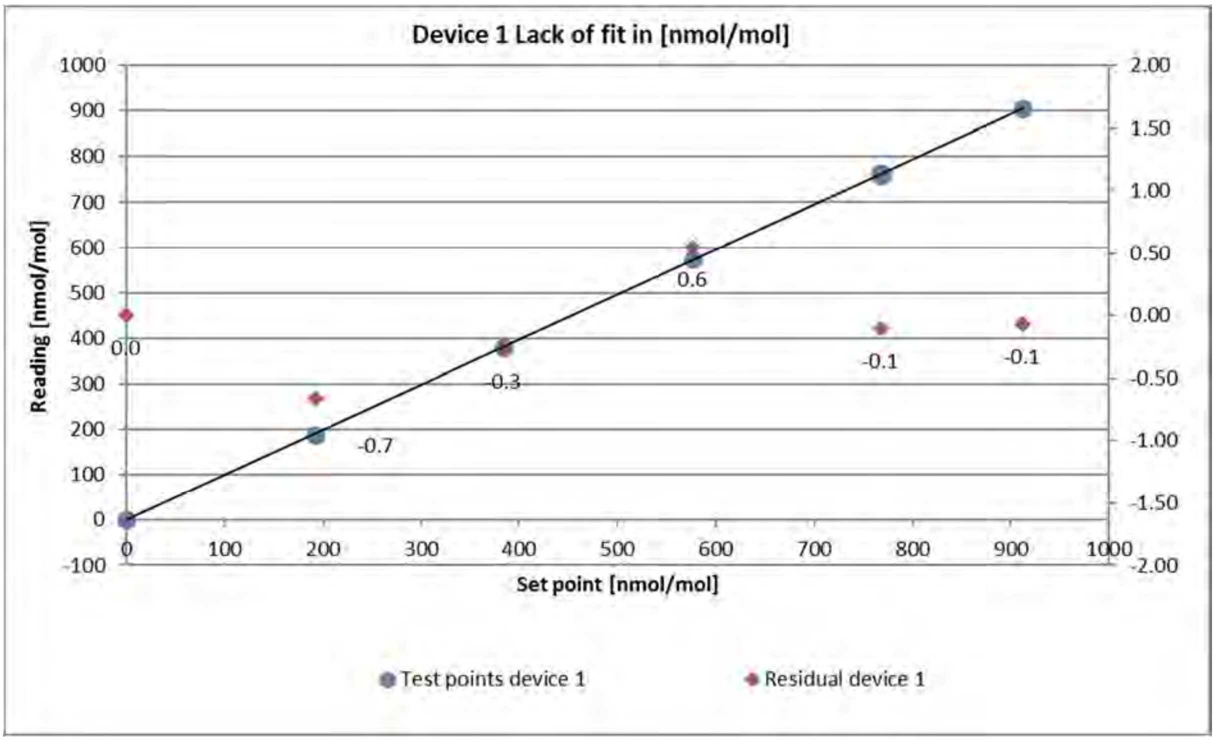


Figure 8: Analytical function obtained from the group averages for system 1 and NO

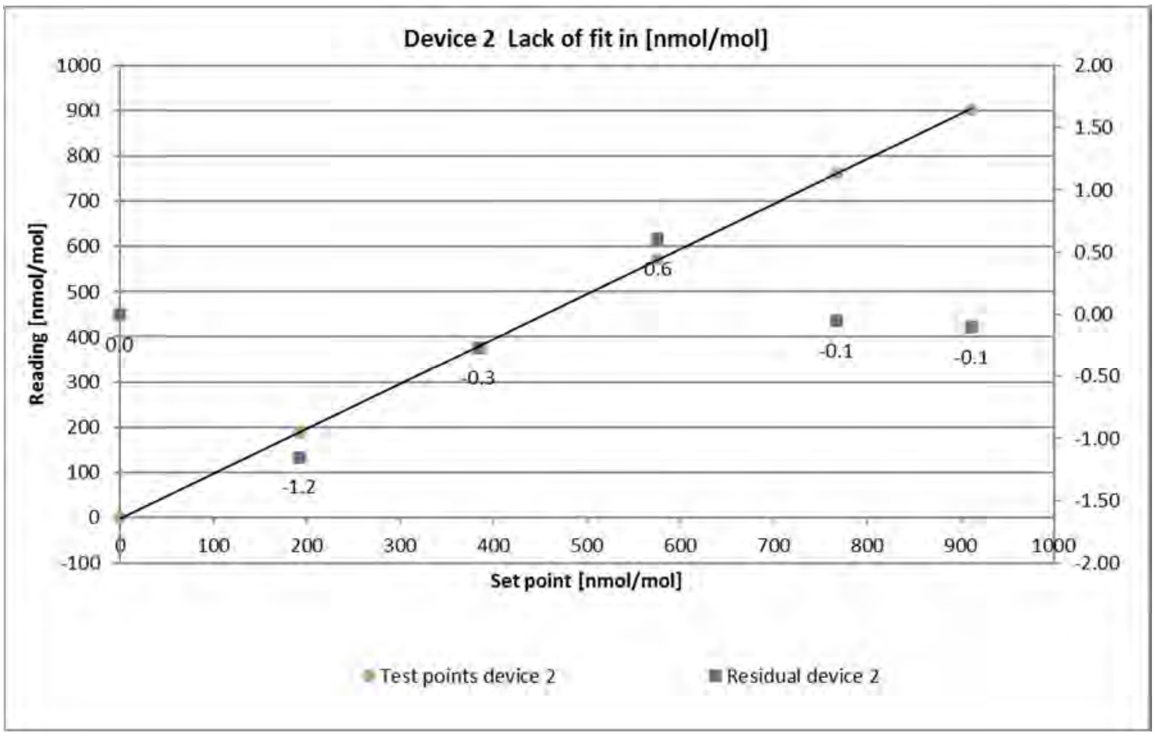


Figure 9: Analytical function obtained from the group averages for system 2 and NO

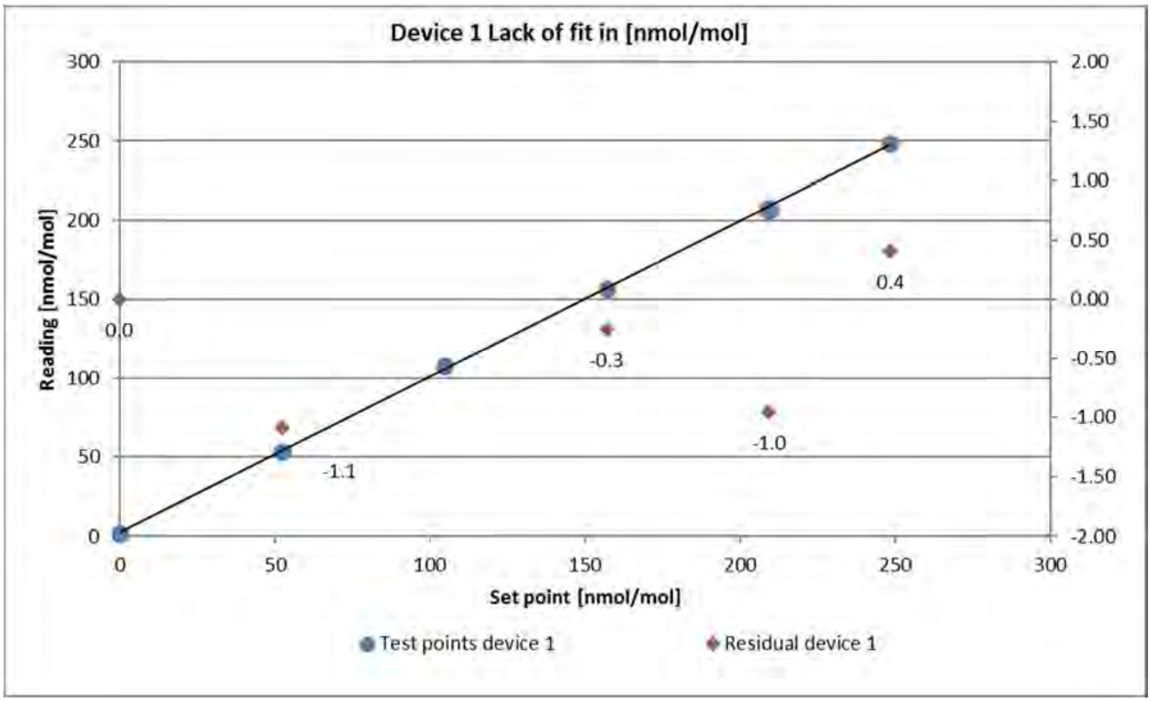


Figure 10: Analytical function obtained from the group averages for system 1 and NO_2

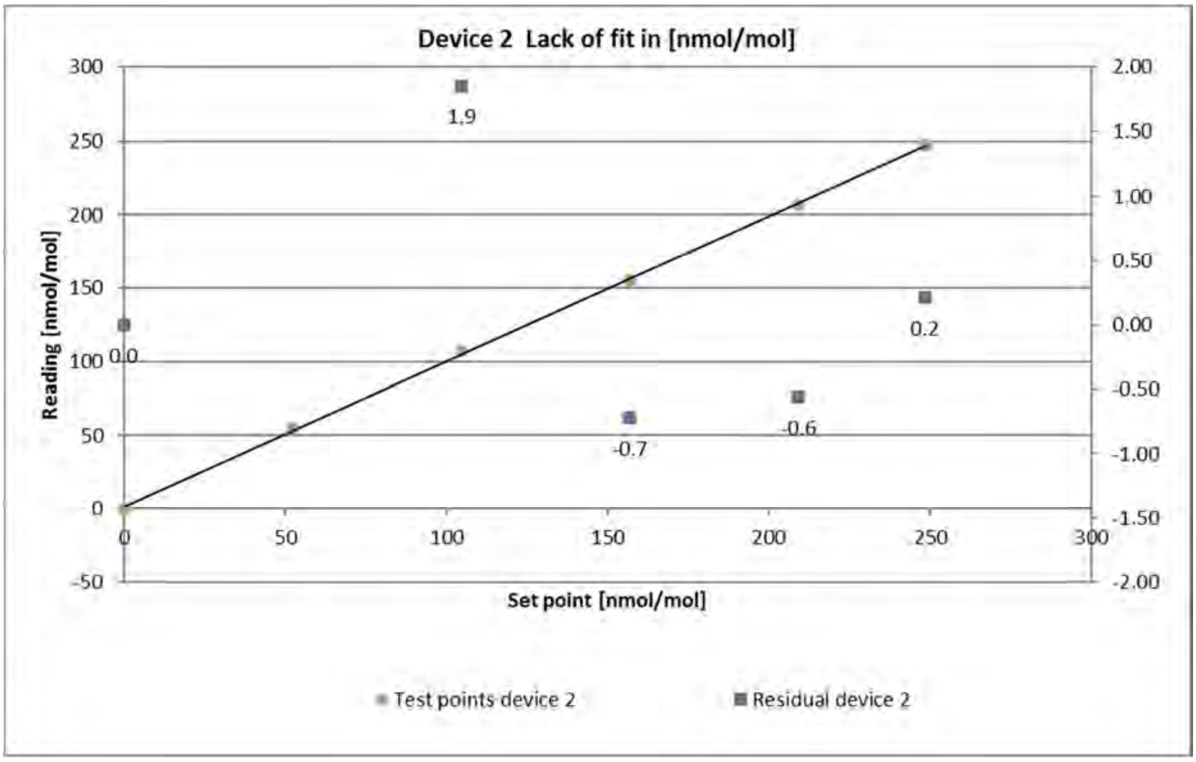


Figure 11: Analytical function obtained from the group averages for system 2 and NO_2

7.5 Assessment

Component NO

The deviation from the linear regression line for instrument 1 is -0.06 nmol/mol at zero point and no more than 0.66% of the target value for concentrations above zero. The deviation from the linear regression line for instrument 2 is -0.70 nmol/mol at zero point and no more than 1.15% of the target value for concentrations above zero.

Component NO_2

The deviation from the linear regression line for instrument 1 is 1.50 nmol/mol at zero point and no more than 2.36% of the target value for concentrations above zero. The deviation from the linear regression line for instrument 2 is -0.24 nmol/mol at zero point and no more than 3.29% of the target value for concentrations above zero.

The residuals from the ideal regression line do not exceed the limit values required by standard EN 14211.

Criterion satisfied? yes

7.6 Detailed presentation of test results

Table 33 and Table 34 present the individual test results.

Table 33: Individual results of the lack-of-fit test for NO

		device 1 [nmol/mol]		device 2 [nmol/mol]	
time	level [%]	actual value y_i	set value x_i	actual value y_i	set value x_i
11:41:00	80	762.10	768.00	761.50	768.00
11:42:00	80	764.10	768.00	763.00	768.00
11:43:00	80	761.20	768.00	760.90	768.00
11:44:00	80	759.80	768.00	759.60	768.00
11:45:00	80	759.30	768.00	758.40	768.00
average		761.30		760.68	
$r_{c,rel}$		-0.11		-0.05	
11:49:00	40	380.70	384.00	379.20	384.00
11:50:00	40	380.10	384.00	378.90	384.00
11:51:00	40	380.10	384.00	378.70	384.00
11:52:00	40	379.40	384.00	378.50	384.00
11:53:00	40	378.30	384.00	377.60	384.00
average		379.72		378.58	
$r_{c,rel}$		-0.27		-0.27	
11:57:00	0	1.00	0.00	0.10	0.00
11:58:00	0	0.20	0.00	-0.60	0.00
11:59:00	0	0.00	0.00	-0.60	0.00
12:00:00	0	-0.80	0.00	-0.70	0.00
12:01:00	0	-0.70	0.00	-1.70	0.00
average		-0.06		-0.70	
r_z					
12:05:00	60	573.40	576.00	573.00	576.00
12:06:00	60	576.60	576.00	574.90	576.00
12:07:00	60	575.10	576.00	574.50	576.00
12:08:00	60	573.80	576.00	574.10	576.00
12:09:00	60	574.10	576.00	572.70	576.00
average		574.60		573.84	
$r_{c,rel}$		0.55		0.60	
12:13:00	20	189.20	192.00	187.50	192.00
12:14:00	20	188.00	192.00	186.00	192.00
12:15:00	20	188.80	192.00	186.80	192.00
12:16:00	20	189.30	192.00	186.50	192.00
12:17:00	20	188.70	192.00	186.60	192.00
average		188.80		186.68	
$r_{c,rel}$		-0.66		-1.15	
12:21:00	95	903.10	912.00	902.60	912.00
12:22:00	95	904.60	912.00	903.60	912.00
12:23:00	95	904.60	912.00	903.00	912.00
12:24:00	95	905.20	912.00	903.10	912.00
12:25:00	95	905.00	912.00	903.70	912.00
average		904.50		903.20	
$r_{c,rel}$		-0.07		-0.10	

Table 34: Individual results of the lack-of-fit test for NO_2

		device 1 [nmol/mol]		device 2 [nmol/mol]	
time	level [%]	actual value y_i	set value x_i	actual value y_i	set value x_i
11:37:00	80	206.20	209.21	207.20	209.21
11:38:00	80	205.90	209.21	206.20	209.21
11:39:00	80	206.00	209.21	206.30	209.21
11:40:00	80	206.80	209.21	207.10	209.21
11:41:00	80	209.00	209.21	208.80	209.21
average		206.78		207.12	
$r_{c,rel}$		-0.95		-0.56	
11:45:00	40	108.90	104.60	107.70	104.60
11:46:00	40	107.70	104.60	106.70	104.60
11:47:00	40	107.90	104.60	106.80	104.60
11:48:00	40	107.50	104.60	106.90	104.60
11:49:00	40	107.30	104.60	106.40	104.60
average		107.86		106.90	
$r_{c,rel}$		2.36		1.85	
11:53:00	0	1.50	0.00	0.10	0.00
11:54:00	0	1.60	0.00	-0.70	0.00
11:55:00	0	1.70	0.00	-0.50	0.00
11:56:00	0	1.50	0.00	-0.30	0.00
11:57:00	0	1.20	0.00	0.20	0.00
average		1.50		-0.24	
r_z					
12:01:00	60	154.50	156.90	153.20	156.90
12:02:00	60	156.60	156.90	154.10	156.90
12:03:00	60	155.90	156.90	156.20	156.90
12:04:00	60	158.30	156.90	157.80	156.90
12:05:00	60	158.10	156.90	156.20	156.90
average		156.68		155.50	
$r_{c,rel}$		-0.26		-0.72	
12:09:00	20	53.20	52.30	53.20	52.30
12:10:00	20	53.30	52.30	55.80	52.30
12:11:00	20	53.80	52.30	55.30	52.30
12:12:00	20	53.00	52.30	55.00	52.30
12:13:00	20	52.40	52.30	55.80	52.30
average		53.14		55.02	
$r_{c,rel}$		-1.08		3.29	
12:17:00	95	247.60	248.43	245.10	248.43
12:18:00	95	246.10	248.43	247.60	248.43
12:19:00	95	248.40	248.43	249.70	248.43
12:20:00	95	250.10	248.43	247.80	248.43
12:21:00	95	250.60	248.43	247.60	248.43
average		248.56		247.56	
$r_{c,rel}$		0.41		0.21	

7.1 8.4.7 Sensitivity coefficient to sample gas pressure

The sensitivity coefficient to sample gas pressure shall be ≤ 8.0 nmol/mol/kPa.

7.2 Test procedures

Measurements are taken at a concentration of about 70% to 80% of the maximum of the certification range of NO at an absolute pressure of about (80 ± 0.2) kPa and at an absolute pressure of about (110 ± 0.2) kPa. At each pressure after waiting the time equivalent to one independent reading, three individual measurements are recorded. From these measurements, the averages at each pressure are calculated.

Measurements at different pressures shall be separated by at least four response times.

The sensitivity coefficient to sample gas pressure is calculated as follows.

$$b_{gp} = \left| \frac{(C_{P2} - C_{P1})}{(P_2 - P_1)} \right|$$

Where:

b_{gp}	is the sample gas pressure sensitivity coefficient;
C_{P1}	is the average concentration of the measurements at sampling gas pressure P_1;
C_{P2}	is the average concentration of the measurements at sampling gas pressure P_2;
P_1	is the minimum sampling gas pressure P_1;
P_2	is the maximum sampling gas pressure P_2.

b_{gp} shall comply with the performance criterion indicated above.

In compliance with the standard, the test has to be performed with the component NO. Pursuant to EN 14211, the test shall be performed at a concentration level of 70% to 80% of the certification range for NO.

In addition, the test was performed for NO_2 at a concentration level of 70% to 80% of the certification range for NO_2.

7.3 Testing

The test was performed in line with the requirements of EN 14211 mentioned before.

Negative pressure was produced by reducing the test gas volume fed by means of blocking the sample gas line. For the positive pressure test, the AMS was connected to a sample gas source. The test gas volume generated was set at a higher rate than the volume sucked in by the analyser. The excess supply was diverted via a tee. The positive pressure was produced by blocking the bypass line. The test gas pressure was determined with the help of a pressure sensor located in the sample gas path.

Individual measurements were performed at concentrations around 70% to 80% of the maximum certification range and sample gas pressures of 80 kPa and 110 kPa.

7.4 Evaluation

The following sensitivity coefficients to sample gas pressure were determined:

Table 35: Sensitivity coefficient to sample gas pressure for NO

	requirement	device 1		device 2	
sensitivity coeff. sample gas pressure b_{gp} [nmol/mol/kPa]	≤ 8.0	0.34	✓	0.43	✓

Table 36: Sensitivity coefficient to sample gas pressure for NO_2

	requirement	device 1		device 2	
sensitivity coeff. sample gas pressure b_{gp} [nmol/mol/kPa]	≤ 8.0	0.19	✓	0.17	✓

7.5 Assessment

For NO, the sensitivity coefficient to sample gas pressure was 0.34 nmol/mol/kPa for instrument 1; for instrument 2 it was 0.43 nmol/mol/kPa.

For NO_2, the sensitivity coefficient to sample gas pressure was 0.19 nmol/mol/kPa for instrument 1; for instrument 2 it was 0.17 nmol/mol/kPa.

Criterion satisfied? yes

7.6 Detailed presentation of test results

Table 37: Individual results of the sensitivity to changes in sample gas pressure for NO

			device 1	device 2
time	pressure [kPa]	concentration	[nmol/mol]	[nmol/mol]
10:28:00	80	720.00	715.40	714.40
10:29:00	80	720.00	715.00	714.80
10:30:00	80	720.00	715.80	714.30
average C_{P1}			715.40	714.50
10:41:00	110	720.00	725.00	727.50
10:42:00	110	720.00	726.20	727.20
10:43:00	110	720.00	725.90	727.40
average C_{P2}			725.70	727.37

Table 38: Individual results of the sensitivity to changes in sample gas pressure for NO_2

			device 1	device 2
time	pressure [kPa]	concentration	[nmol/mol]	[nmol/mol]
10:28:00	80	720.00	192.60	192.20
10:29:00	80	720.00	192.10	192.00
10:30:00	80	720.00	193.00	192.50
average C_{P1}			192.57	192.23
10:41:00	110	720.00	198.30	197.30
10:42:00	110	720.00	198.40	197.50
10:43:00	110	720.00	198.50	197.50
average C_{P2}			198.40	197.43

8.4.8 Sensitivity coefficient to sample gas temperature

The sensitivity coefficient to sample gas temperature shall be ≤ 3.0 µmol/mol/K.

7.2 Test procedures

Measurements shall be performed at sample gas temperatures of $T_{G,1}$ = 0 °C and $T_{G,2}$ = 30 °C. The sensitivity coefficient to sample gas temperature is determined at a concentration of around 70% to 80% of the maximum certification range. Wait the time equivalent to one independent measurement and record three individual measurements at each temperature.

The sample gas temperature, measured at the inlet of the analyser, shall be held constant for at least 30 minutes.

The sensitivity coefficient to sample gas temperature is calculated as follows:

$$b_{gt} = \frac{(C_{GT,2} - C_{GT,1})}{(T_{G,2} - T_{G,1})}$$

Where:

b_{gt} is the sample gas temperature sensitivity coefficient;

$C_{GT,1}$ is the average concentration of the measurements at sample gas temperature $T_{G,1}$;

$C_{GT,2}$ is the average concentration of the measurements at sample gas temperature $T_{G,2}$;

$T_{G,1}$ is the sample gas temperature $T_{G,1}$;

$T_{G,2}$ is the sample gas temperature $T_{G,2}$;

b_{gt} shall comply with the performance criterion indicated above.

In compliance with the standard, the test has to be performed with the component NO. Pursuant to EN 14211, the test shall be performed at a concentration level of 70% to 80% of the certification range for NO.

In addition, the test was performed for NO_2 at a concentration level of 70% to 80% of the certification range for NO_2.

7.3 Testing

The test was performed in line with the requirements of EN 14211 mentioned before.

For the purpose of this test, the test gas mixture was led through a 50 m tube-bundle which was situated in a climatic chamber. The measuring systems were installed directly upstream of the climatic chamber. The end of the tube-bundle was led out of the climatic chamber and connected to the measuring systems. The feed line outside of the climatic chamber was isolated; a thermometer was used to monitor the temperature of the test gas directly upstream of the measuring system. The temperature of the climatic chamber was adjusted so that the gas temperature directly upstream of the analysers was exactly 0 °C. For the purpose of testing a gas temperature of 30 °C, gas was led through a heated line instead of the tube bundle in the climatic chamber.

7.4 Evaluation

Table 39: Sensitivity coefficient to sample gas temperature for NO

	requirement	device 1		device 2	
sensitivity coeff. sample gas temperature b_{gt} [nmol/mol/K]	≤ 3.0	0.08	✓	0.05	✓

Table 40: Sensitivity coefficient to sample gas temperature for NO_2

	requirement	device 1		device 2	
sensitivity coeff. sample gas temperature b_{gt} [nmol/mol/K]	≤ 3.0	0.10	✓	0.10	✓

7.5 Assessment

For instrument 1, the sensitivity coefficient to sample gas temperature was 0.08 nmol/mol/K for NO; for NO_2, it was 0.10 nmol/mol/K.

For instrument 2, the sensitivity coefficient to sample gas temperature was 0.05 nmol/mol/K for NO; for NO_2, it was 0.10 nmol/mol/K.

Criterion satisfied? yes

7.6 Detailed presentation of test results

Table 41: Individual results for the determination of the sensitivity to sample gas temperature for NO

			device 1	device 2
time	temp [ºC]	concentration	[nmol/mol]	[nmol/mol]
07:20:00	0	720.00	722.10	722.10
07:21:00	0	720.00	722.00	722.30
07:22:00	0	720.00	722.80	722.60
average $C_{GT,1}$			722.30	722.33
09:14:00	30	720.00	724.90	723.90
09:15:00	30	720.00	724.80	723.30
09:16:00	30	720.00	724.80	724.60
average $C_{GT,1}$			724.83	723.93

Table 42: Individual results for the determination of the sensitivity to sample gas temperature for NO_2

			device 1	device 2
time	temp [ºC]	concentration	[nmol/mol]	[nmol/mol]
07:33:00	0	200.00	201.10	200.60
07:34:00	0	200.00	201.10	200.00
07:35:00	0	200.00	200.10	200.60
average $C_{GT,1}$			200.77	200.40
09:25:00	30	200.00	203.90	203.30
09:26:00	30	200.00	203.90	203.30
09:27:00	30	200.00	203.70	203.60
average $C_{GT,1}$			203.83	203.40

7.1 8.4.9 Sensitivity coefficient to surrounding temperature

The sensitivity coefficient to surrounding temperature temperature shall be ≤ 3.0 µmol/mol/K.

7.2 Test procedures

The sensitivity of the analyser readings to the surrounding temperature shall be determined by performing measurements at the following temperatures within the specifications of the manufacturer:

1) at the minimum temperature T_{min} = 0 °C;

2) at the temperature T_1 = 20 °C;

3) at the maximum temperature T_{max} = 30 °C.

For these tests, a climate chamber is necessary.

In compliance with the standard, the test has to be performed with the component NO. Pursuant to EN 14211, the test shall be performed at a concentration level of 70% to 80% of the certification range for NO.

At each temperature setting after waiting the time equivalent to one independent measurement, three individual measurements at zero and at span shall be recorded.

The sequence of test temperatures is as follows:

T_l, T_{min}, T_l and T_l, T_{max}, T_l

At the first temperature (T_l), the analyser shall be adjusted at zero and at span level (70% to 80% of the maximum of the certification range). Then three individual measurements are recorded after waiting the time equivalent to one independent reading at T_l, at T_{min} and again at T_l. This measurement procedure shall be repeated at the temperature sequence of T_l, T_{max} and at T_l.

In order to exclude any possible drift due to factors other than temperature, the measurements at T_l are averaged, which is taken into account in the following formula for calculation of the sensitivity coefficient for temperature dependence:

$$b_{st} = \left| \frac{x_T - \frac{x_1 + x_2}{2}}{T_S - T_{S,0}} \right|$$

Where:

b_{st} is the surrounding temperature sensitivity coefficient;

x_T is the average of the measurements at T_{min} or T_{max};

x_1 is the first average of the measurements at T_1;

x_2 is the second average of the measurements at T_1;

T_S is the surrounding temperature in the laboratory;

$T_{S,0}$ is the average of the surrounding temperatures at set point.

For reporting the surrounding temperature dependence the higher value is taken of the two calculations of the temperature dependence at $T_{S,1}$ and $T_{S,2}$.

b_{st} shall comply with the performance criterion indicated above.

7.3 Testing

The test was performed in line with the requirements of EN 14211 mentioned before.

In addition, the test was performed for NO_2 at a concentration level of 70% to 80% of the certification range for NO_2.

7.4 Evaluation

The following sensitivity coefficients to surrounding temperature have been determined:

Table 43: Sensitivity coefficients to surrounding temperature for NO

	requirements	device 1		device 2	
sensitivity coefficient at 0 °C for zero level [nmol/mol/K]	≤ 3.0	0.115	✓	0.127	✓
sensitivity coefficient at 30 °C for zero level [nmol/mol/K]	≤ 3.0	0.067	✓	0.087	✓
sensitivity coefficient at 0 °C for span level [nmol/mol/K]	≤ 3.0	0.249	✓	0.253	✓
sensitivity coefficient at 30 °C for span level [nmol/mol/K]	≤ 3.0	0.250	✓	0.198	✓

Table 44: Sensitivity coefficients to surrounding temperature for NO_2

	requirements	device 1		device 2	
sensitivity coefficient at 0 °C for zero level [nmol/mol/K]	≤ 3.0	0.083	✓	0.106	✓
sensitivity coefficient at 30 °C for zero level [nmol/mol/K]	≤ 3.0	0.075	✓	0.060	✓
sensitivity coefficient at 0 °C for span level [nmol/mol/K]	≤ 3.0	0.197	✓	0.206	✓
sensitivity coefficient at 30 °C for span level [nmol/mol/K]	≤ 3.0	0.168	✓	0.203	✓

As is evident from Table 43 and Table 44, the sensitivity coefficient to the surrounding temperature at zero and at reference point meets the performance criteria.

7.5 Assessment

The sensitivity coefficient to the surrounding temperature b_{st} did not exceed the performance criterion specified at 3.0 nmol/mol/K. For the purpose of uncertainty calculation, the largest value b_{st} is used for both instruments. For NO, this would be 0.250 nmol/mol/K for instrument 1 and 0.253 nmol/mol/K for instrument 2.

For NO_2, this would be 0.197 nmol/mol/K for instrument 1 and 0.206 nmol/mol/K for instrument 2.

Criterion satisfied? yes

7.6 Detailed presentation of test results

Table 45 and Table 46 present the individual test results.

Table 45: Individual test results for the sensitivity coefficient to ambient temperature for NO

	zero level				span level			
			device 1	device 2			device 1	device 2
date	time	temp [ºC]	[nmol/mol]	[nmol/mol]	time	temp [ºC]	[nmol/mol]	[nmol/mol]
19.06.2018	07:31:00	20	-0.2	0.0	07:48:00	20	720.5	720.6
19.06.2018	07:32:00	20	-0.6	0.2	07:49:00	20	720.1	720.8
19.06.2018	07:33:00	20	-0.7	0.3	07:50:00	20	720.1	721.0
average ($X_{1(TS1)}$)			-0.5	0.2			720.2	720.8
19.06.2018	14:14:00	0	-2.6	-1.8	14:29:00	0	714.6	716.0
19.06.2018	14:15:00	0	-2.8	-2.5	14:30:00	0	715.8	716.0
19.06.2018	14:16:00	0	-2.2	-2.6	14:31:00	0	715.7	715.8
average($X_{Ts,1}$)		0	-2.5	-2.3			715.4	715.9
20.06.2018	14:00:00	20	0.1	0.2	14:15:00	20	720.4	721.0
20.06.2018	14:01:00	20	0.0	0.3	14:16:00	20	720.6	721.2
20.06.2018	14:02:00	20	0.0	0.4	14:17:00	20	720.4	721.4
average ($X_{2(TS1)}$) = ($X_{1(TS2)}$)			0.0	0.3			720.5	721.2
20.06.2018	07:19:00	30	0.8	1.1	07:34:00	30	723.6	722.7
20.06.2018	07:20:00	30	0.7	1.2	07:35:00	30	723.0	722.5
20.06.2018	07:21:00	30	0.8	1.2	07:36:00	30	722.8	722.7
average($X_{Ts,2}$)			0.8	1.2			723.1	722.6
21.06.2018	13:49:00	20	0.1	0.3	14:04:00	20	721.0	720.4
21.06.2018	13:50:00	20	0.2	0.3	14:05:00	20	720.8	720.1
21.06.2018	13:51:00	20	0.2	0.3	14:06:00	20	720.6	719.8
average ($X_{2(TS2)}$)			0.2	0.3			720.8	720.1

Table 46: Individual test results for the sensitivity coefficient to the surrounding temperature for NO_2

	zero level				span level			
			device 1	device 2			device 1	device 2
date	time	temp [ºC]	[nmol/mol]	[nmol/mol]	time	temp [ºC]	[nmol/mol]	[nmol/mol]
19.06.2018	07:31:00	20	-0.2	0.2	08:05:00	20	191.1	189.8
19.06.2018	07:32:00	20	-0.4	0.2	08:06:00	20	190.6	189.4
19.06.2018	07:33:00	20	-0.6	0.5	08:07:00	20	190.5	190.0
average ($X_{1(TS1)}$)			-0.4	0.3			190.7	189.7
19.06.2018	14:14:00	0	-1.6	-1.6	14:45:00	0	186.6	185.9
19.06.2018	14:15:00	0	-1.4	-1.8	14:46:00	0	186.4	185.6
19.06.2018	14:16:00	0	-2.1	-1.9	14:47:00	0	186.4	185.8
average($X_{Ts,1}$)		0	-1.7	-1.8			186.5	185.8
20.06.2018	14:00:00	20	0.2	0.5	14:30:00	20	189.7	190.1
20.06.2018	14:01:00	20	0.4	0.4	14:31:00	20	190.2	190.0
20.06.2018	14:02:00	20	0.4	0.3	14:32:00	20	190.3	190.0
average ($X_{2(TS1)}$) = ($X_{1(TS2)}$)			0.3	0.4			190.1	190.0
20.06.2018	07:19:00	30	1.1	0.9	07:50:00	30	191.4	191.9
20.06.2018	07:20:00	30	1.0	1.0	07:51:00	30	191.5	192.0
20.06.2018	07:21:00	30	1.2	1.1	07:52:00	30	192.6	191.5
average($X_{Ts,2}$)			1.1	1.0			191.8	191.8
01.01.2013	13:49:00	20	0.4	0.5	14:20:00	20	190.1	189.4
01.01.2013	13:50:00	20	0.4	0.6	14:21:00	20	190.4	189.7
01.01.2013	13:51:00	20	0.3	0.1	14:22:00	20	190.2	189.4
average ($X_{2(TS2)}$)			0.4	0.4			190.2	189.5

7.1 8.4.10 Sensitivity coefficient to electrical voltage

The sensitivity coefficient to electrical voltage shall not exceed 0.3 nmol/mol/V.

7.2 Test procedures

The sensitivity coefficient of electrical voltage shall be determined at both ends of the voltage range specified by the manufacturer, V_1 and V_2, at zero concentration and at a concentration around 70% to 80% of the maximum of the certification range of NO. After waiting the time equivalent to one independent measurement, three individual measurements at each voltage and concentration level shall be recorded.

The sensitivity coefficient to electrical voltage in accordance with EN 14211 is calculated as follows:

$$b_v = \left| \frac{(C_{V2} - C_{V1})}{(V_2 - V_1)} \right|$$

Where:

b_v is the voltage sensitivity coefficient,

C_{V1} is the average concentration reading of the measurements at voltage V_1

C_{V2} is the average concentration reading of the measurements at voltage V_2

V_1 is the minimum voltage V_{min}

V_2 is the maximum voltage V_{max}

For reporting the dependence on voltage, the higher value of the result at zero and span level shall be taken.

b_v shall comply with the performance criterion indicated above.

7.3 Testing

For the purpose of determining the sensitivity coefficient to electrical voltage, a transformer was looped into the measuring system's voltage supply. Test gases were applied to the zero and reference point at various voltages.

The test was performed in line with the requirements of EN 14211 mentioned before.

In addition, the test was performed for NO_2 at a concentration level of 70% to 80% of the certification range for NO_2.

7.4 Evaluation

The following sensitivity coefficients to electrical voltage have been determined:

Table 47: Sensitivity coefficient to electrical voltage for NO

	requirement	device 1		device 2	
sensitivity coeff. of voltage b_v at zero level [nmol/mol/V]	≤ 0.3	0.01	✓	0.00	✓
sensitivity coeff. of voltage b_v at span level [nmol/mol/V]	≤ 0.3	0.00	✓	0.00	✓

Table 48: Sensitivity coefficient to electrical voltage for NO_2

	requirement	device 1		device 2	
sensitivity coeff. of voltage b_v at zero level [nmol/mol/V]	≤ 0.3	0.00	✓	0.01	✓
sensitivity coeff. of voltage b_v at span level [nmol/mol/V]	≤ 0.3	0.00	✓	0.02	✓

7.5 Assessment

At no test item did the sensitivity coefficient to electrical voltage b_v exceed the value of 0.3 nmol/mol/V specified in standard EN 14211. For the purpose of uncertainty calculation, the largest b_v is used for both instruments. For NO, this is 0.01 nmol/mol/V for instrument 1 and 0.00 nmol/mol/V for instrument 2.

For NO_2, this is 0.00 nmol/mol/V for instrument 1 and 0.02 nmol/mol/V for instrument 2.

Criterion satisfied? yes

7.6 Detailed presentation of test results

Table 49: Individual results of the sensitivity coefficient to electrical voltage for NO

			device 1	device 2
time	voltage [V]	concentration	[nmol/mol]	[nmol/mol]
10:54:00	207	0	-0.4	-0.4
10:55:00	207	0	0.3	-0.1
10:56:00	207	0	0.3	-0.1
average C_{V1} at zero			0.07	-0.20
11:04:00	253	0	0.2	0.3
11:05:00	253	0	0.3	-0.2
11:06:00	253	0	1.0	-0.5
average C_{V2} at zero			0.50	-0.13
11:18:00	207	720.00	723.1	719.1
11:19:00	207	720.00	723.6	719.4
11:20:00	207	720.00	723.3	719.5
average C_{V1} at Span			723.33	719.33
11:28:00	253	720.00	723.6	719.1
11:29:00	253	720.00	723.4	719.6
11:30:00	253	720.00	723.4	719.1
average C_{V2} at Span			723.47	719.27

Table 50: Individual results of the sensitivity coefficient to electrical voltage for NO_2

			device 1	device 2
time	voltage [V]	concentration	[nmol/mol]	[nmol/mol]
10:54:00	207	0	0.9	0.3
10:55:00	207	0	0.4	0.5
10:56:00	207	0	0.2	0.8
average C_{V1} at zero			0.50	0.53
11:04:00	253	0	0.5	0.5
11:05:00	253	0	0.8	0.9
11:06:00	253	0	0.2	1.1
average C_{V2} at zero			0.50	0.83
11:18:00	207	200.00	200.6	200.8
11:19:00	207	200.00	200.2	200.6
11:20:00	207	200.00	200.1	200.6
average C_{V1} at Span			200.30	200.67
11:28:00	253	200.00	200.1	201.8
11:29:00	253	200.00	200.2	201.4
11:30:00	253	200.00	200.7	201.6
average C_{V2} at Span			200.33	201.60

7.1 8.4.11 Interferents

Interferents at zero and at concentration c_t for NO (500 ± 50 nmol/mol). Deviations for interferents H_2O, CO_2 and NH_3 shall not exceed 5.0 nmol/mol.

7.2 Test procedures

The analyser response to certain interferents shall be tested. The interferents can give a positive or negative response. The test shall be performed at zero and at an NO test concentration (c_t) of (500 ± 50) nmol/mol.

The concentration of the mixtures of the test gases with the interferent shall have an expanded uncertainty of ≤ 5% and shall be traceable to nationally accepted standards. The interferents to be tested and their respective concentrations are given in Table 51. The influence of each interferent shall be determined separately. A correction on the concentration of the measurand shall be made for the dilution effect due to addition of an interferent (e.g. water vapour).

After adjustment of the analyser at zero and span level, the analyser shall be fed with a mixture of zero gas and the interferent to be investigated with the concentration as given in Table Table 51. With this mixture, one independent measurement of NO followed by two individual measurements of NO shall be carried out. This procedure shall be repeated with a mixture of the measurand at concentration c_t and the interferent to be investigated. The influence quantities at zero and concentration c_t are calculated from:

$$X_{\mathrm{int},z} = x_z$$

$$X_{\mathrm{int},ct} = x_{ct} - c_t$$

Where:

$X_{\mathrm{int},z}$ is the influence quantity of the interferent at zero;

x_z is the average of the measurements of NO at zero;

$X_{\mathrm{int},ct}$ is the influence quantity of the interferent at concentration c_t;

x_{ct} is the average of the measurements of NO at concentration c_t

c_t is the applied concentration at the one-hour limit value.

The influence quantities of the interferents shall comply with the performance criteria indicated above, both at zero and at concentration c_t.

7.3 Testing

The test was performed in line with the requirements of EN 14211 mentioned before. The instruments are adjusted at zero and at the concentration c_t. Zero and test gas with the various interfering components were then applied. The interferents listed in Table 51 were applied in the concentrations indicated.As required by standard EN 14211, the measured NOx concentration shall be used instead of the NO concentration when testing the interferent NH_3.

In addition, the test was also performed for NO_2 at the zero point and at a span concentration at the level of the 1h limit value for NO_2 (104 nmol/mol).

As the measuring system does not use the standard reference method as its measuring principle, in addition to the three interfering substances specified in EN 14211, further interferents potentially present in ambient air were tested for their effects. Chapter 6.1 7.4.11 Cross sensitivity presents the results of these additional tests.

Table 51: Interferents in accordance with EN 14211

Interferent	Value
H_2O	19 mmol/mol
CO_2	500 µmol/mol
NH_3	200 nmol/mol

7.4 Evaluation

The following overview presents the influence quantities of each interfering substance. When determining the influence of moisture, the dilution effect which occurs inside the test gas generation system was also taken into account.

Table 52: Influence of the tested interferents for NO (c_t = 500±50 nmol/mol)

	requirements	**device 1**		**device 2**	
influence quantity interferent H_2O at zero [nmol/mol/V]	≤ 5.0 nmol/mol	1.87	✓	0.33	✓
influence quantity interferent H_2O at c_t [nmol/mol/V]	≤ 5.0 nmol/mol	2.37	✓	2.80	✓
influence quantity interferent CO_2 at zero [nmol/mol/V]	≤ 5.0 nmol/mol	1.27	✓	1.03	✓
influence quantity interferent CO_2 at c_t [nmol/mol/V]	≤ 5.0 nmol/mol	-0.07	✓	-0.33	✓
influence quantity interferent NH_3 at zero [nmol/mol/V]	≤ 5.0 nmol/mol	1.37	✓	1.67	✓
influence quantity interferent NH3 at c_t [nmol/mol/V]	≤ 5.0 nmol/mol	2.13	✓	0.97	✓

Table 53: Influence of the tested

	requirements	**device 1**		**device 2**	
influence quantity interferent H_2O at zero [nmol/mol/V]	≤ 5.0 nmol/mol	0.07	✓	0.23	✓
influence quantity interferent H_2O at c_t [nmol/mol/V]	≤ 5.0 nmol/mol	2.27	✓	2.13	✓
influence quantity interferent CO_2 at zero [nmol/mol/V]	≤ 5.0 nmol/mol	-0.07	✓	0.07	✓
influence quantity interferent CO_2 at c_t [nmol/mol/V]	≤ 5.0 nmol/mol	-0.57	✓	0.37	✓
influence quantity interferent NH_3 at zero [nmol/mol/V]	≤ 5.0 nmol/mol	0.97	✓	0.93	✓
influence quantity interferent NH3 at c_t [nmol/mol/V]	≤ 5.0 nmol/mol	0.83	✓	0.80	✓

7.5 Assessment

At zero point the result for the interference were 1.87 nmol/mol (AMS 1) and 0.33 nmol/mol (AMS 2) for H_2O, 1.27 nmol/mol (AMS 1) and 1.03 nmol/mol (AMS 2) for CO_2 and finally 1.37 nmol/mol (AMS 1) and 1.67 nmol/mol (AMS 2) for NH_3. At zero point the result for the interference were 0.07 nmol/mol (AMS 1) and 0.23 nmol/mol (AMS 2) for H_2O, -0.07 nmol/mol (AMS 1) and 0.07 nmol/mol (AMS 2) for CO_2 and finally 0.97 nmol/mol (AMS 1) and 0.93 nmol/mol (AMS 2) for NH_3.

The following results were obtained for the cross-sensitivity at the limit value c_t: NO: 2.37 nmol/mol for instrument 1 and 2.80 nmol/mol for instrument 2; H_2O: -0.07 nmol/mol for instrument 1 and -0.33 nmol/mol for instrument 2; CO_2 and 2.13 nmol/mol for instrument 1 and 0.97 nmol/mol at NH_3. The following results were obtained for the cross-sensitivity at the limit value c_t: NO_2: 2.27 nmol/mol for instrument 1 and 2.13 nmol/mol for instrument 2; H_2O: -0.57 nmol/mol for instrument 1 and 0.37 nmol/mol for instrument 2; CO_2 and 0.83 nmol/mol for instrument 1 and 0.80 nmol/mol at NH_3.

Criterion satisfied? yes

7.6 Detailed presentation of test results

Table 54 and Table 55 present the individual test results.

Table 54: Individual results for testing interferents for NO

	without interferents			with interferents		
	time	device 1	device 2	time	device 1	device 2
zero gas + H_2O (19 mmol/mol)	14:10:00	-0.50	0.90	14:22:00	1.80	0.90
	14:11:00	-0.70	0.90	14:23:00	1.30	0.90
	14:12:00	-0.20	0.10	14:24:00	1.10	1.10
	average x_z	-0.47	0.63	average x_z	1.40	0.97
test gas c_t + H_2O (19 mmol/mol)	14:37:00	504.60	502.10	14:57:00	507.90	504.50
	14:38:00	505.40	501.60	14:58:00	506.90	505.20
	14:39:00	504.10	502.50	14:59:00	506.40	504.90
	average x_{ct}	504.70	502.07	average x_{ct}	507.07	504.87
zero gas + CO_2 (500 µmol/mol)	15:50:00	-0.10	0.20	16:00:00	0.70	1.40
	15:51:00	-0.50	0.10	16:01:00	0.90	1.60
	15:52:00	-0.20	0.50	16:02:00	1.40	0.90
	average x_z	-0.27	0.27	average x_z	1.00	1.30
test gas c_t + CO_2 (500 µmol/mol)	16:17:00	502.10	503.70	16:27:00	501.70	502.90
	16:18:00	502.00	503.50	16:28:00	501.90	503.40
	16:19:00	502.10	503.50	16:29:00	502.40	503.40
	average x_{ct}	502.07	503.57	average x_{ct}	502.00	503.23
zero gas + NH_3 (200 nmol/mol)	13:26:00	0.00	0.00	13:36:00	1.80	1.80
	13:27:00	0.70	0.20	13:37:00	1.70	2.10
	13:28:00	0.50	0.30	13:38:00	1.80	1.60
	average x_z	0.40	0.17	average x_z	1.77	1.83
test gas c_t + NH_3 (200 nmol/mol)	13:51:00	503.80	506.30	14:01:00	506.40	507.40
	13:52:00	504.30	505.50	14:02:00	507.00	507.70
	13:53:00	505.70	507.50	14:03:00	506.80	507.10
	average x_{ct}	506.73	506.43	average x_{ct}	506.73	507.40

NO_x reading with interference from NH_3

Table 55: Individual results for testing interferents for NO_2

	without interferents			with interferents		
	time	device 1	device 2	time	device 1	device 2
zero gas + H_2O (19 mmol/mol)	14:10:00	0.20	0.00	14:22:00	0.30	0.60
	14:11:00	0.40	0.30	14:23:00	0.30	0.10
	14:12:00	0.50	0.00	14:24:00	0.70	0.30
	average x_z	0.37	0.10	average x_z	0.43	0.33
test gas c_t + H_2O (19 mmol/mol)	15:15:00	105.30	103.90	15:35:00	107.10	106.80
	15:16:00	105.50	105.10	15:36:00	107.60	106.60
	15:17:00	104.40	104.50	15:37:00	107.30	106.50
	average x_{ct}	105.07	104.50	average x_{ct}	107.33	106.63
zero gas + CO_2 (500 µmol/mol)	15:50:00	0.40	0.00	16:00:00	0.30	0.30
	15:51:00	0.70	0.00	16:01:00	0.00	0.30
	15:52:00	0.30	0.80	16:02:00	0.90	0.40
	average x_z	0.47	0.27	average x_z	0.40	0.33
test gas c_t + CO_2 (500 µmol/mol)	16:39:00	103.70	103.60	19:49:00	103.20	103.70
	16:40:00	104.60	103.10	16:50:00	104.00	103.60
	16:41:00	104.60	103.30	16:51:00	104.00	103.80
	average x_{ct}	104.30	103.33	average x_{ct}	103.73	103.70
zero gas + NH_3 (200 nmol/mol)	13:26:00	0.20	0.70	13:36:00	1.40	1.60
	13:27:00	0.30	0.20	13:37:00	1.50	1.60
	13:28:00	0.90	0.90	13:38:00	1.40	1.40
	average x_z	0.47	0.60	average x_z	1.43	1.53
test gas c_t + NH_3 (200 nmol/mol)	14:22:00	102.80	104.80	14:32:00	103.00	105.50
	14:23:00	102.10	104.50	14:33:00	103.30	105.20
	14:24:00	102.80	104.80	14:34:00	103.90	105.80
	average x_{ct}	103.40	104.70	average x_{ct}	103.40	105.50

NO_x reading with interference from NH_3

7.1 8.4.12 Averaging test

The averaging effect shall not exceed 7% of the measured value.

7.2 Test conditions

The averaging test gives a measure of the uncertainty in the averaged values caused by short-term concentration variations in the sampled air shorter than the time scale of the measurement process in the analyser. In general, the output of an analyser is a result of the determination of a reference concentration (normally zero) and the actual concentration which takes a certain time.

For the determination of the uncertainty due to the averaging, the following concentrations are applied to the analyser and readings are taken at each concentration:

- a constant concentration of NO_2 at a concentration $c_{t,}NO_2$ which is about twice the hourly limit value; and
- a stepwise varied concentration of NO between zero and 600 nmol/mol (concentration $c_{t,NO}$).

The time period (t_c) of the constant NO concentration shall be at least equal to a period necessary to obtain four independent readings (which is equal to at least sixteen response times). The time period (t_v) of the varying NO concentration shall be at least equal to a period to obtain four independent readings. The time period (t_{NO}) for the NO concentration shall be 45 s followed by a period (t_{zero}) of 45 s of zero concentration. Further:

c_t is the test concentration;

t_v is a time period including a whole number of t_{NO} and t_{zero} pairs, and contains a minimum of 3 such pairs.

The change from t_{NO} to t_{zero} shall be within 0.5 s. The change from t_C to t_V shall be within one response time of the analyser under test.

The averaging effect (E_{av}) is calculated according to:

$$E_{av} = \frac{C_{const}^{av} - 2C_{\mathrm{var}}^{av}}{C_{const}^{av}} * 100$$

Where:

E_{av} is the averaging effect (%);

C_{const}^{av} is the average of the at least four independent measurements during the variable concentration period;

C_{var}^{av} 0x1is the average of the at least four independent measurements during the variable concentration period;

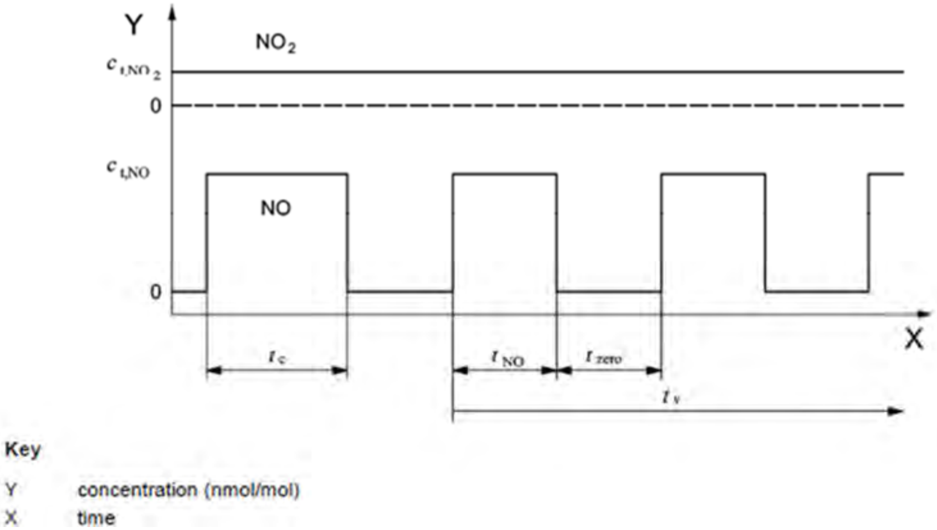


Figure 12: Test of the averaging effect (t_{NO} = t_{zero} = 45 s.)

7.3 Testing

The averaging test was performed in compliance with the requirements specified in EN 14211. With the help of a mass flow controller we applied a step change of the NO concentration between zero and 600 nmol/mol and, at the same time, a constant NO_2 concentration $c_{t,}NO_2$ of roughly twice the hourly limit value. First, the average was calculated at a constant test gas concentration. Then, a three-way valve served to switch between zero and test gas every 45 s. During that period of alternating test gas application the average was calculated again.

In addition, the test was also performed for NO_2 between zero and at a span concentration at the level of the 1h limit value for NO_2 (104 nmol/mol).

7.4 Evaluation

The following averages were determined during the test:

Table 56: Results of the averaging test for NO

	requirement	device 1		device 2	
averaging effect E_{av} [%]	≤ 7%	0.5	✓	3.8	✓

This results in the following averaging effects:

System 1 0.5%

System 2 3.8%

Table 57: Results of the averaging test for NO_2

	requirement	device 1		device 2	
averaging effect E_{av} [%]	≤ 7%	3.4	✓	1.6	✓

This results in the following averaging effects:

System 1 3.4%

System 2 1.6%

7.5 Assessment

The performance criterion specified by standard EN 14211 is fully satisfied.

Criterion satisfied? yes

7.6 Detailed presentation of test results

Table 58 and Table 59 present the individual results of the averaging test.

Table 58: Individual results of the averaging test for NO

		device 1	device 2
	time	[nmol/mol]	[nmol/mol]
average constant concentration $C_{av,c}$	07:15:00	590.5	588.1
	till		
	07:34:00		
average variable concentration $C_{av,c}$	07:35:00	291.2	279.4
	till		
	07:54:00		

		device 1	device 2
	time	[nmol/mol]	[nmol/mol]
average constant concentration $C_{av,c}$	08:05:00	592.2	590.4
	till		
	08:24:00		
average variable concentration $C_{av,c}$	08:25:00	302.1	290.1
	till		
	08:44:00		

		device 1	device 2
	time	[nmol/mol]	[nmol/mol]
average constant concentration $C_{av,c}$	08:56:00	594.4	592.7
	till		
	09:15:00		
average variable concentration $C_{av,c}$	09:16:00	290.7	282.3
	till		
	09:35:00		

Table 59: Individual results of the averaging test for NO_2

		device 1	device 2
	time	[nmol/mol]	[nmol/mol]
average constant concentration $C_{av,c}$	10:37:00	105.9	108.0
	till		
	10:56:00		
average variable concentration $C_{av,c}$	10:57:00	50.6	52.8
	till		
	11:16:00		

		device 1	device 2
	time	[nmol/mol]	[nmol/mol]
average constant concentration $C_{av,c}$	11:27:00	109.6	111.8
	till		
	11:46:00		
average variable concentration $C_{av,c}$	11:47:00	53.9	55.8
	till		
	12:06:00		

		device 1	device 2
	time	[nmol/mol]	[nmol/mol]
average constant concentration $C_{av,c}$	12:18:00	110.3	112.6
	till		
	12:37:00		
average variable concentration $C_{av,c}$	12:38:00	52.9	54.9
	till		
	12:57:00		

7.1 8.4.13 Difference sample/calibration port

The difference between sample and calibration port shall not exceed 1.0%.

7.2 Test procedures

If the analyser has different ports for feeding sample gas and calibration gas, the difference in response of the analyser to feeding through the sample or calibration port shall be tested. The test shall be carried out by feeding the analyser with a test gas with a concentration of 70% to 80% of the maximum of the certification range of NO through the sample port. The test shall consist of one independent measurement followed by two individual measurements. After a period of at least four response times, the test shall be repeated using the calibration port. The difference shall be calculated according to:

$$\Delta x_{SC} = \frac{x_{sam} - x_{cal}}{c_t} \times 100$$

Where:

Δx_{SC}	is the difference sample/calibration port;
x_{sam}	is the average of the measured concentration using the sample port;
x_{cal}	is the average of the measured concentration using the calibration port;
c_t	is the concentration of the test gas;
Δ_{SC}	shall comply with the performance criterion indicated above.

7.3 Testing

The measuring system is not equipped with a test gas inlet separate from the sample gas inlet. Test gases have to be fed via the sample inlet.

7.4 Evaluation

Not applicable

7.5 Assessment

This test criterion does not apply. The measuring system is not equipped with a test gas inlet separate from the sample gas inlet. Test gases have to be fed via the sample inlet.

Criterion satisfied? not applicable

7.6 Detailed presentation of test results

Not applicable

7.1 8.4.14 Converter efficiency

The converter efficiency should be at least 98%.

7.2 Test procedures

The converter efficiency is determined by measurements with calculated amounts of NO_2. This can be achieved by means of gas-phase titration of NO to NO_2 with ozone.

The test shall be performed at two concentration levels: at about 50% and about 95% of the maximum of the certification range of NO_2.

The NO_x measuring system shall be calibrated applying an NO concentration of about 70% to 80% of the maximum certification range for NO to the NO and NO_x channels. Both channels need to be adjusted to display the same value. The values shall be recorded.

A known NO concentration at 50% of the NO certification range is applied to the measuring system until a stable signal is obtained This stable period shall be at least as long as four response times. Four individual readings each are performed at the NO and the NO_x channel. Then, NO is brought to react with O_3 to produce NO_2. This mixture containing a constant NO_x concentration is applied to the measuring system until the output signal has stabilised. This stable period shall be at least four response times of the measuring system under test; the NO concentration after gas-phase titration shall be between 10% and 20% of the original NO concentration. Then, four individual readings each are performed at the NO and the NO_x channel. Then, the O_3 supply is cut and only NO is applied to the measuring system until the output signal has stabilised again. This stable period shall be at least as long as four response times of the measuring system. After that the average of the four individual measurements at the NO and the NO_x channel is calculated.

The converter efficiency is calculated as follows:

$$E_{conv} = \left(1 - \frac{(NO_x)_i - (NO_x)_f}{(NO)_i - (NO)_f} \right) \times 100\%$$

Where:

E_{conv}	is the converter efficiency in %;
$(NO_x)_i$	is the average of the four individual measurements at the NOx channel at the initial NOx concentration;
$(NO_x)_f$	is the average of the four individual measurements at the NO_x channel at the resulting NO_x concentration after applying O_3;
$(NO)_i$	is the average of the four individual measurements at the NO channel at the initial NO concentration;
$(NO)_f$	is the average of the four individual measurements at the NO channel at the resulting NO concentration after applying O_3;

The lowest value of the two converter efficiencies shall be reported.

7.3 Testing

The Model 405 nm measuring system does not use the EU reference method chemiluminescence as its measuring principle. This is why the measuring system does not have a standard NO-NO_2 converter. The Model 405 nm monitor directly analyses NO_2 in the UV range. NO is determined by oxidising sample air with ozone at alterating cycles. The difference between the two measurements is indicated as NO value. Even though the measuring system does not have a converter, the test was performed as described above in order to demonstrate that NO and NO_2 measurements are equivalent to the standard reference method.

The test was performed in compliance with the requirements specified in EN 14211. When applying test gas two NO_2 concentrations in the range of 50% to 95% of the certification range for NO_2 were adjusted by means of gas-phase titration.

The converter efficiency was determined in the laboratory.

7.4 Evaluation

During the test, the following converter efficiencies were determined for the two Model 405 nm measuring systems. The lowest value of the two NO_2 concentration is reported below.

	requirement	device 1		device 2	
converter efficiency E_c [%]	≥ 98%	99.8	✓	99.6	✓

7.5 Assessment

At a converter efficiency of 99.6%, the performance criterion specified by EN 14211 is fully satisfied.

Criterion satisfied? yes

7.6 Detailed presentation of test results

Table 60 presents the individual values.

Table 60: Individual results for the converter efficiency

				device 1		device 2	
	time	O_3 [nmol/mol]	NO_2 [nmol/mol]	NO [nmol/mol]	NO_x [nmol/mol]	NO [nmol/mol]	NO_x [nmol/mol]
	08:45:00	start					
O_3=0, NO=50%	08:57:00	0.0	0.3	482.2	482.5	481.6	482.2
	09:01:00	0.0	0.4	482.4	482.8	481.9	482.1
	09:05:00	0.0	0.4	482.6	483.0	482.1	482.4
	09:21:00	0.0	0.2	482.2	482.4	482.3	482.4
average		0.0	0.3	482.4	482.7	482.0	482.3
NO_2= 50% 130.75	09:37:00	131.0	128.9	353.7	482.5	353.9	481.6
	09:41:00	131.0	129.1	352.8	482.1	353.1	481.5
	09:45:00	131.0	129.0	353.9	482.6	352.8	481.9
	10:01:00	131.0	129.4	353.2	482.4	353.4	482.1
average		131.0	129.1	353.4	482.4	353.3	481.8
O_3=0, NO=50%	10:47:00	0.0	0.1	479.5	479.6	480.5	480.2
	10:51:00	0.0	0.2	479.6	479.8	480.2	480.4
	10:55:00	0.0	0.2	479.6	479.8	480.3	480.4
	10:59:00	0.0	0.3	479.9	480.2	480.4	480.2
average		0.0	0.2	479.7	479.9	480.4	480.3
NO_2= 95% 248.43	11:15:00	248.0	245.0	234.8	480.6	235.6	481.2
	11:19:00	248.0	244.8	234.1	480.6	235.2	481.0
	11:23:00	248.0	244.1	234.8	480.4	235.2	481.0
	11:27:00	248.0	244.6	234.6	480.6	235.1	480.7
average		248.0	244.6	234.6	480.6	235.3	481.0
O_3=0, NO=50%	11:43:00	0.0	0.3	481.2	481.6	480.4	481.0

7.1 8.4.15 Residence time in the analyser

The residence time in the analyser shall be ≤ 3.0 s.

7.2 Test procedures

The residence time inside the analyser shall be calculated on the basis of the flow and the volumes of the tubing and other relevant components inside the analyser.

7.3 Testing

The gas volume of the Model 405 nm measuring system is approximately 30.0 ml from the sample inlet to the measuring cell. The measured sample gas flow is at 1.5 l/min. This results in a residence time in the analyser of 1.2 s.

7.4 Evaluation

Not applicable.

7.5 Assessment

Residence time in the analyser was 1.2 s.

Criterion satisfied? yes

7.6 Detailed presentation of test results

Not applicable.

7.1 8.5.4 Long-term drift

The long-term drift at zero point shall not exceed ≤ 5.0 nmol/mol.
Long-term drift at span level shall not exceed 5% of the certification range.

7.2 Test procedures

After each bi-weekly zero and span check, the drift of the analysers under test shall be calculated at zero and at span following the procedures as given below. If the drift compared to the initial calibration exceeds one of the performance criteria for drift at zero or span level, the “period of unattended operation” equals the number of weeks until the observation of the infringement, minus two weeks. For further (uncertainty) calculations, the values for “long term drift” are the values for zero and span drift over the period of unattended operation.

At the beginning of the drift period, five individual measurements were performed at zero and span level following the calibration (after waiting the time equivalent to a single independent reading).

The long-term drift is calculated as follows:

$$D_{L,Z} = (C_{Z,1} - C_{Z,0})$$

Where:

$D_{L,Z}$ is the drift at zero;

$C_{Z,0}$ is the average concentration of the measurements at zero at the beginning of the drift period;

$C_{Z,1}$ is the average concentration of the measurements at zero at the end of the drift period;

$D_{L,Z}$ shall comply with the performance criterion indicated above.

$$D_{L,S} = \frac{(C_{S,1} - C_{S,0}) - D_{L,Z}}{C_{S,1}} \times 100$$

Where:

$D_{L,S}$ is the drift at span concentration c_t;

$C_{S,0}$ 0 is the average concentration of the measurements at span level at the beginning of the drift period;

$C_{S,1}$ is the average concentration of the measurements at span level at the end of the drift period;

$D_{L,S}$ shall comply with the performance criterion indicated above.

7.3 Testing

For the purpose of this test, test gas was applied every other week. Table 61 and Table 62 report the measured values for bi-weekly test gas applications. In compliance with the standard, the test has to be performed with the component NO. Pursuant to EN 14211, the test shall be performed at a concentration level of 70% to 80% of the certification range for NO.

In addition, the test was performed for NO_2 at a concentration level of 70% to 80% of the certification range for NO_2.

7.4 Evaluation

Table 61: Results for the long-term drift at zero point for NO

		requierment	Device 1		Device 2	
average start $C_{z,1}$ at zero [nmol/mol]	23.07.2018	≤ 5.0	--	✓	--	✓
long term drift $D_{L,Z}$ at zero [nmol/mol]	06.08.2018	≤ 5.0	0.23	✓	0.94	✓
long term drift $D_{L,Z}$ at zero [nmol/mol]	20.08.2018	≤ 5.0	0.13	✓	0.38	✓
long term drift $D_{L,Z}$ at zero [nmol/mol]	03.09.2018	≤ 5.0	-0.37	✓	0.18	✓
long term drift $D_{L,Z}$ at zero [nmol/mol]	17.09.2018	≤ 5.0	0.27	✓	0.54	✓
long term drift $D_{L,Z}$ at zero [nmol/mol]	01.10.2018	≤ 5.0	-0.03	✓	0.66	✓
long term drift $D_{L,Z}$ at zero [nmol/mol]	15.10.2018	≤ 5.0	0.39	✓	0.08	✓
long term drift $D_{L,Z}$ at zero [nmol/mol]	29.10.2018	≤ 5.0	-0.01	✓	-0.46	✓

Table 62: Results for the long-term drift at reference point for NO

		requierment	Device 2 1		Device 2	
average start $C_{s,1}$ at span [nmol/mol]	23.07.2018	≤ 5 %	--	✓	--	✓
long term drift $D_{L,S}$ at span [nmol/mol]	06.08.2018	≤ 5 %	0.33	✓	-0.17	✓
long term drift $D_{L,S}$ at span [nmol/mol]	20.08.2018	≤ 5 %	0.24	✓	0.01	✓
long term drift $D_{L,S}$ at span [nmol/mol]	03.09.2018	≤ 5 %	0.49	✓	0.61	✓
long term drift $D_{L,S}$ at span [nmol/mol]	17.09.2018	≤ 5 %	1.02	✓	0.12	✓
long term drift $D_{L,S}$ at span [nmol/mol]	01.10.2018	≤ 5 %	0.97	✓	0.68	✓
long term drift $D_{L,S}$ at span [nmol/mol]	15.10.2018	≤ 5 %	1.00	✓	0.62	✓
long term drift $D_{L,S}$ at span [nmol/mol]	29.10.2018	≤ 5 %	1.29	✓	0.89	✓

Table 63: Results for the long-term drift at zero point for NO_2

		requierment	Device 1		Device 2	
average start $C_{z,1}$ at zero [nmol/mol]	23.07.2018	≤ 5.0	--	✓	--	✓
long term drift $D_{L,Z}$ at zero [nmol/mol]	06.08.2018	≤ 5.0	-0.61	✓	-0.09	✓
long term drift $D_{L,Z}$ at zero [nmol/mol]	20.08.2018	≤ 5.0	0.17	✓	0.53	✓
long term drift $D_{L,Z}$ at zero [nmol/mol]	03.09.2018	≤ 5.0	0.27	✓	-0.05	✓
long term drift $D_{L,Z}$ at zero [nmol/mol]	17.09.2018	≤ 5.0	0.03	✓	0.29	✓
long term drift $D_{L,Z}$ at zero [nmol/mol]	01.10.2018	≤ 5.0	0.21	✓	0.47	✓
long term drift $D_{L,Z}$ at zero [nmol/mol]	15.10.2018	≤ 5.0	0.09	✓	0.01	✓
long term drift $D_{L,Z}$ at zero [nmol/mol]	29.10.2018	≤ 5.0	0.09	✓	0.11	✓

Table 64: Results for the long-term drift at reference point for NO_2

		requierment	Device 2 1		Device 2	
average start $C_{s,1}$ at span [nmol/mol]	23.07.2018	≤ 5 %	--	✓	--	✓
long term drift $D_{L,S}$ at span [nmol/mol]	06.08.2018	≤ 5 %	0.06	✓	0.00	✓
long term drift $D_{L,S}$ at span [nmol/mol]	20.08.2018	≤ 5 %	-0.48	✓	-0.04	✓
long term drift $D_{L,S}$ at span [nmol/mol]	03.09.2018	≤ 5 %	-0.61	✓	1.29	✓
long term drift $D_{L,S}$ at span [nmol/mol]	17.09.2018	≤ 5 %	-0.12	✓	1.33	✓
long term drift $D_{L,S}$ at span [nmol/mol]	01.10.2018	≤ 5 %	-0.01	✓	0.69	✓
long term drift $D_{L,S}$ at span [nmol/mol]	15.10.2018	≤ 5 %	-0.26	✓	1.23	✓
long term drift $D_{L,S}$ at span [nmol/mol]	29.10.2018	≤ 5 %	0.61	✓	0.98	✓

7.5 Assessment

Maximum long-term drift at zero point $D_{l,z}$ for NO was at 0.39 nmol/mol for instrument 1 and 0.94 nmol/mol for instrument 2. Maximum long-term drift at reference point $D_{l,s}$ for NO was at 1.29% for instrument 1 and 0.89% for instrument 2.

Maximum long-term drift at zero point $D_{l,z}$ for NO_2 was at -0.61 nmol/mol for instrument 1 and 0.53 nmol/mol for instrument 2. Maximum long-term drift at reference point $D_{l,s}$ for NO_2 was at 0.61% for instrument 1 and 1.33% for instrument 2.

Criterion satisfied? yes

7.6 Detailed presentation of test results

Table 65 and Table 66 present the individual values obtained for the determination of the long-term drift.

Table 65: Individual results of the drift check for NO

Zero Concentration			
		Device 1	Device 2
Date	Time	[nmol/mol]	[nmol/mol]
23.07.2018	10:22:00	1.00	0.20
	10:23:00	1.00	-0.20
	10:24:00	0.20	0.10
	Mittel	0.73	0.03
	10:26:00	0.20	-0.50
	10:27:00	0.30	0.30
	10:28:00	0.40	-0.30
	Mittel	0.30	-0.17
	10:30:00	-0.20	1.00
	10:31:00	0.30	-0.20
	10:32:00	0.20	0.50
	Mittel	0.10	0.43
	10:34:00	0.20	0.40
	10:35:00	-0.10	0.10
	10:36:00	0.20	0.20
	Mittel	0.10	0.23
	10:38:00	0.30	0.50
	10:39:00	0.10	0.20
	10:40:00	0.20	0.40
		0.20	0.37
Average field start $c_{z,0}$		**0.29**	**0.18**
06.08.2018	10:28:00	0.40	2.90
	10:29:00	1.20	0.60
	10:30:00	-0.50	0.60
	10:31:00	0.40	0.80
	10:32:00	1.10	0.70
	aver. cz,1	**0.52**	**1.12**
20.08.2018	14:24:00	0.60	0.20
	14:25:00	0.30	0.50
	14:26:00	0.40	0.70
	14:27:00	0.10	0.60
	14:28:00	0.70	0.80
	aver. cz,1	**0.42**	**0.56**
03.09.2018	12:10:00	0.10	0.40
	12:11:00	1.30	0.30
	12:12:00	-1.90	0.60
	12:13:00	0.10	0.30
	12:14:00	0.00	0.20
	aver. cz,1	**-0.08**	**0.36**
17.09.2018	10:38:00	0.50	0.80
	10:39:00	0.40	0.70
	10:40:00	1.20	0.70
	10:41:00	0.40	0.60
	10:42:00	0.30	0.80
	aver. cz,1	**0.56**	**0.72**
01.10.2018	15:51:00	0.30	0.90
	15:52:00	0.30	1.20
	15:53:00	0.10	0.50
	15:54:00	0.20	0.70
	15:55:00	0.40	0.90
	aver. cz,1	**0.26**	**0.84**
15.10.2018	10:12:00	0.80	0.00
	10:13:00	0.90	0.00
	10:14:00	0.30	0.70
	10:15:00	0.50	0.20
	10:16:00	0.90	0.40
	aver. cz,1	**0.68**	**0.26**
29.10.2018	13:25:00	0.60	-1.00
	13:26:00	0.10	0.20
	13:27:00	0.00	1.10
	13:28:00	0.10	-0.70
	13:29:00	0.60	-1.00
	aver. cz,1	**0.28**	**-0.28**

C_t-Concentration			
		Device 1	Device 2
Date	Time	[nmol/mol]	[nmol/mol]
23.07.2018	10:50:00	718.90	722.60
	10:51:00	719.00	722.90
	10:52:00	718.80	722.50
	Mittel	718.90	722.67
	10:54:00	718.60	722.20
	10:55:00	719.10	722.70
	10:56:00	718.80	722.90
	Mittel	718.83	722.60
	10:58:00	719.10	722.90
	10:59:00	719.10	722.90
	11:00:00	720.00	722.20
	Mittel	719.40	722.67
	11:02:00	718.70	722.30
	11:03:00	719.60	722.20
	11:04:00	719.00	721.90
	Mittel	719.10	722.13
	11:06:00	719.70	722.30
	11:07:00	719.10	722.50
	11:08:00	719.30	722.50
		719.37	722.43
Average field start $c_{s,0}$		**719.12**	**722.50**
06.08.2018	10:43:00	722.80	722.90
	10:44:00	721.60	722.10
	10:45:00	721.70	722.60
	10:46:00	721.10	722.20
	10:47:00	721.40	721.30
	Mittel cs,1	**721.72**	**722.22**
20.08.2018	14:39:00	720.90	723.90
	14:40:00	720.00	722.20
	14:41:00	721.80	723.50
	14:42:00	720.00	722.70
	14:43:00	722.20	722.50
	aver. cs,1	**720.98**	**722.96**
03.09.2018	12:25:00	722.30	727.10
	12:26:00	723.70	727.30
	12:27:00	721.80	727.10
	12:28:00	721.40	727.10
	12:29:00	722.40	727.10
	aver. cs,1	**722.32**	**727.14**
17.09.2018	10:53:00	726.30	725.70
	10:54:00	725.00	724.30
	10:55:00	727.70	724.80
	10:56:00	727.70	721.30
	10:57:00	727.50	723.40
	aver. cs,1	**726.84**	**723.90**
01.10.2018	16:06:00	724.40	728.30
	16:07:00	725.30	727.20
	16:08:00	727.80	727.60
	16:09:00	727.10	729.20
	16:10:00	726.20	728.20
	aver. cs,1	**726.16**	**728.10**
15.10.2018	10:27:00	726.40	725.20
	10:28:00	727.50	726.90
	10:29:00	727.20	728.60
	10:30:00	726.70	728.00
	10:31:00	726.20	726.70
	aver. cs,1	**726.80**	**727.08**
29.10.2018	13:40:00	727.20	727.70
	13:41:00	727.00	727.80
	13:42:00	728.80	728.80
	13:43:00	729.00	730.20
	13:44:00	730.40	728.00
	aver. cs,1	**728.48**	**728.50**

Table 66: Individual results of the drift check for NO_2

Zero Concentration			
		Device 1	Device 2
Date	Time	[nmol/mol]	[nmol/mol]
23.07.2018	10:22:00	0.10	0.20
	10:23:00	0.20	-0.10
	10:24:00	0.30	-0.20
	Mittel	0.20	-0.03
	10:26:00	0.90	-0.10
	10:27:00	0.20	0.40
	10:28:00	0.40	-0.30
	Mittel	0.50	0.00
	10:30:00	0.10	-1.00
	10:31:00	0.10	1.00
	10:32:00	0.10	-0.30
	Mittel	0.10	-0.10
	10:34:00	0.10	0.90
	10:35:00	0.20	0.20
	10:36:00	0.10	0.90
	Mittel	0.13	0.67
	10:38:00	0.10	-0.20
	10:39:00	0.00	0.40
	10:40:00	0.30	0.80
		0.13	0.33
Average field start $c_{z,0}$		**0.21**	**0.17**
06.08.2018	10:30:00	-0.10	-0.70
	10:31:00	-0.70	-0.10
	10:32:00	-0.70	0.00
	10:33:00	-0.30	0.60
	10:34:00	-0.20	0.60
	aver. cz,1	**-0.40**	**0.08**
20.08.2018	14:24:00	0.10	0.00
	14:25:00	0.30	1.20
	14:26:00	0.40	0.90
	14:27:00	0.20	0.80
	14:28:00	0.90	0.60
	aver. cz,1	**0.38**	**0.70**
03.09.2018	12:10:00	0.10	0.00
	12:11:00	0.70	0.90
	12:12:00	0.80	-0.30
	12:13:00	0.00	0.00
	12:14:00	0.80	0.00
	aver. cz,1	**0.48**	**0.12**
17.09.2018	10:38:00	0.20	0.50
	10:39:00	0.10	0.30
	10:40:00	0.60	0.70
	10:41:00	0.30	0.40
	10:42:00	0.00	0.40
	aver. cz,1	**0.24**	**0.46**
01.10.2018	15:51:00	0.60	0.60
	15:52:00	0.30	0.50
	15:53:00	0.50	0.70
	15:54:00	0.30	0.60
	15:55:00	0.40	0.80
	aver. cz,1	**0.42**	**0.64**
15.10.2018	10:12:00	0.70	0.00
	10:13:00	0.60	0.30
	10:14:00	0.20	0.20
	10:15:00	0.10	0.10
	10:16:00	-0.10	0.30
	aver. cz,1	**0.30**	**0.18**
29.10.2018	13:25:00	0.10	0.30
	13:26:00	0.40	0.80
	13:27:00	0.30	0.00
	13:28:00	0.60	0.00
	13:29:00	0.10	0.30
	aver. cz,1	**0.30**	**0.28**

C_t-Concentration			
		Device 1	Device 2
Date	Time	[nmol/mol]	[nmol/mol]
23.07.2018	11:20:00	207.50	203.90
	11:21:00	206.30	205.70
	11:22:00	207.90	203.80
	Mittel	207.23	204.47
	11:24:00	205.40	202.40
	11:25:00	203.40	205.40
	11:26:00	207.20	204.90
	Mittel	205.33	204.23
	11:28:00	207.20	204.80
	11:29:00	207.60	203.30
	11:30:00	205.20	204.40
	Mittel	206.67	204.17
	11:32:00	207.20	206.90
	11:33:00	205.70	205.70
	11:34:00	207.30	202.80
	Mittel	206.73	205.13
	11:36:00	206.50	206.40
	11:37:00	205.60	205.40
	11:38:00	207.20	206.90
		206.43	206.23
Average field start $c_{s,0}$		**206.48**	**204.85**
06.08.2018	10:58:00	207.90	204.80
	10:59:00	205.60	204.30
	11:00:00	205.90	202.40
	11:01:00	203.40	205.40
	11:02:00	207.20	206.90
	Mittel cs,1	**206.00**	**204.76**
20.08.2018	14:50:00	204.80	205.60
	14:51:00	206.20	205.40
	14:52:00	205.50	205.40
	14:53:00	205.90	204.80
	14:54:00	205.90	205.30
	aver. cs,1	**205.66**	**205.30**
03.09.2018	12:36:00	206.10	207.50
	12:37:00	204.60	206.60
	12:38:00	206.60	207.50
	12:39:00	204.80	208.20
	12:40:00	205.40	207.60
	aver. cs,1	**205.50**	**207.48**
17.09.2018	11:04:00	206.60	208.60
	11:05:00	206.90	205.80
	11:06:00	208.20	208.50
	11:07:00	205.30	207.70
	11:08:00	204.30	208.90
	aver. cs,1	**206.26**	**207.90**
01.10.2018	16:17:00	205.20	206.80
	16:18:00	207.30	206.40
	16:19:00	207.40	205.60
	16:20:00	206.60	207.80
	16:21:00	206.80	207.10
	aver. cs,1	**206.66**	**206.74**
15.10.2018	10:38:00	207.70	208.20
	10:39:00	204.70	206.20
	10:40:00	206.30	209.50
	10:41:00	205.10	208.20
	10:42:00	206.40	204.90
	aver. cs,1	**206.04**	**207.40**
29.10.2018	13:51:00	206.30	207.00
	13:52:00	207.40	207.00
	13:53:00	207.90	206.10
	13:54:00	209.50	207.60
	13:55:00	208.10	207.20
	aver. cs,1	**207.84**	**206.98**

7.1 8.5.5 Reproducibility standard deviation for NO_2 under field conditions

Reproducibility standard deviation under field conditions shall not exceed 5% of the mean value over a period of three months.

7.2 Test procedures

The reproducibility standard deviation under field conditions is calculated from the measured hourly averaged data during the three-month period.

The difference $\Delta x_{f,i}$ for each (ith) parallel measurement is calculated from:

$$\Delta x_{f,i} = x_{f,1,i} - x_{f,2,i}$$

Where:

$\Delta x_{f,i}$ is the ith difference in a parallel measurement;

$x_{f,1,i}$ is the ith measurement result of analyser 1;

$x_{f,2,i}$ is the ith measurement result of analyser 2;

The reproducibility standard deviation under field conditions is calculated according to:

$$s_{r,f} = \frac{\left(\sqrt{\frac{\sum_{i=1}^{n} \Delta x_{f,i}^{2}}{2*n}}\right)}{c_f} \times 100$$

Where:

$s_{r,f}$ is the reproducibility standard deviation for NO_2 under field conditions (%);

n is the number of parallel measurements;

c_f is the average concentration of nitrogen dioxide measured during the field test;

The reproducibility standard deviation under field conditions, $s_{r,f}$, shall comply with the performance criterion indicated above.

7.3 Testing

The reproducibility standard deviation under field conditions for NO_2 was calculated from the hourly averages over the field test period according to the equation stated above.

7.4 Evaluation

Table 67: Determination of the reproducibility standard deviation for NO_2 on the basis of complete field test data

reproducibility standard deviation in field		
no. of measurments (1h- average)	[n]	2359
average of both analyzers (3 month)	[nmol/mol]	15.96
standard deviation from paired measurements	[nmol/mol]	0.544
reproducibility standard deviation in field $S_{r,f}$	**[%]**	**3.41**
requirement	≤ 5.0 %	✓

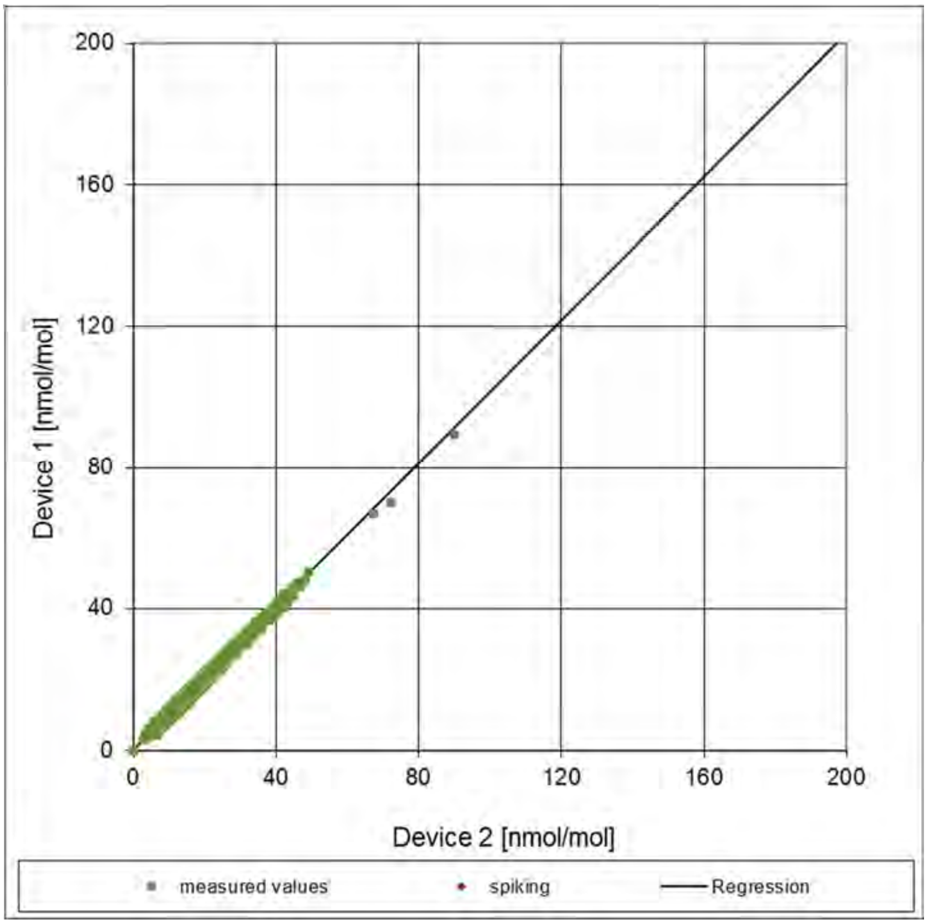


Figure 13: Diagram illustrating the reproducibility standard deviation for NO_2 under field conditions

The reproducibility standard deviation for NO_2 under field conditions is at 3.41% of the average. This is the value used for the total uncertainty calculation in accordance with EN 14211.

7.5 Assessment

The reproducibility standard deviation for NO_2 under field conditions was 3.41% as a percentage of the mean value over the three-months field test period. Thus, the requirements of EN 14211 are satisfied.

Criterion satisfied? yes

7.6 Detailed presentation of test results

For a better overview, we present the results of the reproducibility standard deviation for NO. In compliance with EN 14211, the assessment of the reproducibility standard deviation is performed in the field with NO_2. The following data is provided for information only.

Table 68: Determination of the reproducibility standard deviation for NO on the basis of complete field test data

reproducibility standard deviation in field		
no. of measurments (1h- average)	[n]	2359
average of both analyzers (3 month)	[nmol/mol]	29.57
standard deviation from paired measurements	[nmol/mol]	1.116
reproducibility standard deviation in field $S_{r,f}$	**[%]**	**3.78**
requirement	≤ 5.0 %	✓

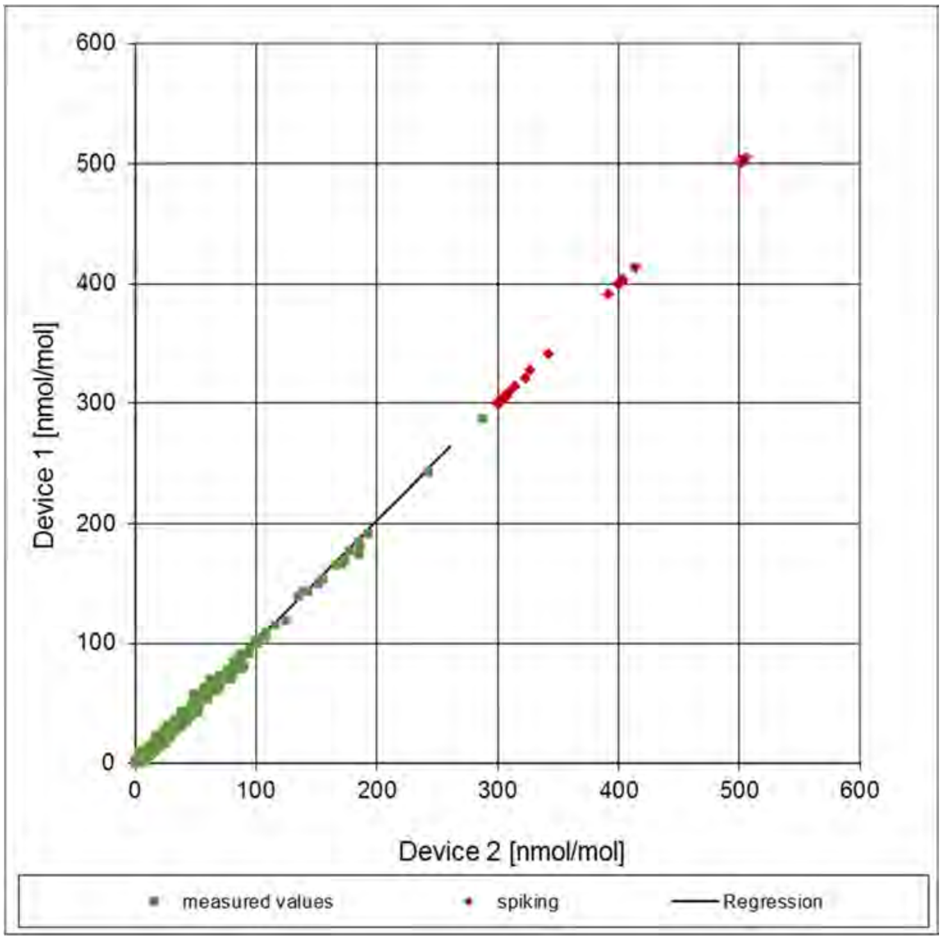


Figure 14: Diagram illustrating the reproducibility standard deviation for NO under field conditions

7.1 8.5.6 Inspection interval

The period of unattended operation of the AMS shall be at least 2 weeks.

7.2 Equipment

Not required for this performance criterion

7.3 Testing

With regard to this minimum requirement, the maintenance tasks required in a specific period and the length of that period for the correct functioning of the measuring system were identified. Furthermore, in determining the maintenance interval, the drift determined for zero and reference point in accordance with 7.1 8.5.4 Long-term drift have been taken into consideration.

7.4 Evaluation

Over the entire period of the field test, no unacceptable drift was observed. The maintenance interval is thus determined by the necessary maintenance works.

During the three months field test period, maintenance is generally limited to contamination and plausibility checks and potential status/error messages. Naturally, the frequency of filter replacement will depend on the ambient dust concentration at the site of installation. Chapter 5 of the manual and Chapter 8 of this report provide information about tasks to be performed in the maintenance interval.

7.5 Assessment

The necessary maintenance tasks determine the period of unattended operation. In essence, these include contamination checks, plausibility checks and checks of potential status/error warnings. The external particle filter needs replacing at the measurement site after having been subjected to dust loading. EN 14211 requires checking of zero and span points at least once every two weeks.

Criterion satisfied? yes

7.6 Detailed presentation of test results

Not applicable in this instance.

7.1 8.5.7 Period of availability of the analyser

Availability of the analyser shall be at least 90%.

7.2 Test procedures

The correct operation of the analysers shall be checked at least every fourteen days. It is recommended to perform this check every day during the first fourteen days. These checks consist of plausibility checks on the measured values, as well as, when available, on status signals and other relevant parameters. Time, duration and nature of any malfunctioning shall be logged.

The total time period with useable measuring data is the period during the field test during which valid measuring data of the ambient air concentrations are obtained. In this time period, the time needed for calibrations, conditioning of sample systems and filters and maintenance shall not be included.

The availability of the analyser is calculated as:

$$A_a = \frac{t_u}{t_t} * 100$$

Where:

A_a is the availability of the analyser (%);

t_u is the total time period with validated measuring data;

t_t is the time period of the field test minus the time for calibration, conditioning and maintenance, t_u and t_t shall be expressed in the same units.

The availability shall comply with the performance criterion indicated above.

7.3 Testing

Using the equation given above, the availability was calculated from the total period of the field test and the outage times which have occurred during this period.

Evaluation

Outage times which have occurred during the field test are listed in Table 69.

Table 69: Availability of the Model 405 nm measuring system

		System 1	System 2
Operation time	h	2359	2359
Outage time	h	0	0
Maintenance time	h	12	12
Actual operating time:	h	2347	2347
Actual operating time incl. maintenance times:	h	2359	2359
Availability	%	100	100

Maintenance times were caused by daily test gas feeding for the purpose of determining the drift behaviour and the maintenance interval and by times needed for replacing the Teflon filter built into the sample gas path.

7.5 Assessment

The availability is 100%. Thus, the requirement of EN 14211 is satisfied.

Criterion satisfied? yes

7.6 Detailed presentation of test results

Not applicable.

7.1 8.6 Calculation of the total uncertainty in accordance with standard EN 14211 (2012)

The type approval of the analyser consists of the following steps:

***1)** The value of each individual performance characteristic tested in the laboratory shall fulfil the criterion stated in Table E.1 of standard EN 14211.*

***2)** The expanded uncertainty calculated from the standard uncertainties due to the values of the specific performance characteristics obtained in the laboratory tests shall fulfil the criterion as stated in Annex I of Directive 2008/50/EC (15% for fixed measurements or 25% for indicative measurements). This criterion is the maximum uncertainty of individual measurements for continuous measurements at the 1-hour limit value. The relevant specific performance characteristics and the calculation procedure are given in Annex E of standard EN 14211.*

3) The value of each of the individual performance characteristics tested in the field shall fulfil the criterion stated in Table E.1 of EN 14211.

4) The expanded uncertainty calculated from the standard uncertainties due to the values of the specific performance characteristics obtained in the laboratory and field tests shall fulfil the criterion as stated in Annex I of Directive 2008/50/EC (15% for fixed measurements or 25% for indicative measurements). This criterion is the maximum uncertainty of individual measurements for continuous measurements at the 1-hour limit value. The relevant specific performance characteristics and the calculation procedure are given in Annex E of standard EN 14211.

7.2 Equipment

Calculation of the total uncertainty in accordance with standard EN 14211 (2012), Annex E

7.3 Testing

At the end of the performance test, the total uncertainties were calculated from the values obtained during the test.

7.4 Evaluation

Regarding 1) The value of each performance characteristic tested in the laboratory tests fulfils the criterion stated in Table E.1 of EN 14211.

Regarding 2) The expanded uncertainty calculated from the standard uncertainties due to the values of the specific performance characteristics obtained in the laboratory tests fulfils the criterion as stated.

Regarding 3) The value of each performance characteristic tested in the field tests fulfils the criterion stated in Table E.1 of EN 14211.

Regarding 4) The expanded uncertainty calculated from the standard uncertainties due to the values of the specific performance characteristics obtained in the laboratory and field tests fulfils the criterion as stated.

7.5 Assessment

The requirement regarding the expanded uncertainty of the measuring system is complied with.

Criterion satisfied? yes

7.6 Detailed presentation of test results

Table 70 summarises the results for items 1 and 3.

Table 71 and Table 73 contain the results regarding item 2.

Table 72 and Table 74 contain the results regarding item 4.

Table 70: Relevant performance characteristics and criteria according to EN 14211

Performance characteristic	Performance criterion	Test result	Satisfied	Page
8.4.5 Repeatability standard deviation at zero	≤ 1.0 nmol/mol	S_r system 1: 0.67 nmol/mol (NO) S_r system 2: 0.50 nmol/mol (NO) S_r system 1: 0.35 nmol/mol (NO_2) S_r system 2: 0.57 nmol/mol (NO_2)	yes	98
8.4.5 Repeatability standard deviation at concentration level c_t	≤ 3.0 nmol/mol	S_r system 1: 1.07 nmol/mol (NO) S_r system 2: 1.03 nmol/mol (NO) S_r system 1: 0.88 nmol/mol (NO_2) S_r system 2: 0.78 nmol/mol (NO_2)	yes	98
8.4.6 “Lack of fit” (deviation from the linear regression)	Largest deviation from the linear regression function > 0, ≤ 4.0% of the reading Residual at zero: ≤ 5 nmol/mol	$X_{l,z}$ Analyser 1: ZP -0.06 nmol/mol (NO) X_l Analyser 1: RP 0.66% (NO) $X_{l,z}$ Analyser 2: ZP -0.70 nmol/mol (NO) X_l Analyser 2: RP 1.15% (NO) $X_{l,z}$ Analyser 1: ZP 1.50 nmol/mol (NO_2) X_l Analyser 1: RP 2.36% (NO_2) $X_{l,z}$ Analyser 2: ZP -0.24 nmol/mol (NO_2) X_l Analyser 2: RP 3.29% (NO_2)	yes	102
8.4.7 Sensitivity coefficient of sample gas pressure	≤ 8.0 nmol/mol/kPa	b_{gp} Analyser 1: 0.34 nmol/mol/kPa (NO) b_{gp} Analyser 2: 0.43 nmol/mol/kPa (NO) b_{gp} Analyser 1: 0.19 nmol/mol (NO_2) b_{gp} Analyser 2: 0.17 nmol/mol (NO_2)	yes	109
8.4.8 Sensitivity coefficient of sample gas temperature	≤ 3.0 nmol/mol/K	b_{gt} Analyser 1: 0.08 nmol/mol/K (NO) b_{gt} Analyser 2: 0.05 nmol/mol/K (NO) b_{gt} Analyser 1: 0.10 nmol/mol/K (NO_2) b_{gt} Analyser 2: 0.10 nmol/mol/K (NO_2)	yes	112
8.4.9 Sensitivity coefficient of surrounding temperature	≤ 3.0 nmol/mol/K	b_{st} Analyser 1: 0.250 nmol/mol/K (NO) b_{st} Analyser 2: 0.253 nmol/mol/K (NO) b_{st} Analyser 1: 0.197 nmol/mol/K (NO_2) b_{st} Analyser 2: 0.206 nmol/mol/K (NO_2)	yes	115

Performance characteristic	**Performance criterion**	**Test result**	**Satisfied**	**Page**
8.4.10 Sensitivity coefficient of electrical voltage	≤ 0.3 nmol/mol/V	b_v Analyser 1: RP 0.01 nmol/mol/V (NO) b_v Analyser 2: RP 0.00 nmol/mol/V (NO) b_v Analyser 1: RP 0.00 nmol/mol/V (NO_2) b_v Analyser 2: RP 0.02 nmol/mol/V (NO_2)	yes	119
8.4.11 Interferent at zero and at concentration level c_t	H_2O ≤ 5.0 nmol/mol CO_2 ≤ 5.0 nmol/mol NH3 ≤ 5.0 nmol/mol	NO channel - H_2O System 1 ZP 1.87 nmol/mol / RP 2.37 nmol/mol System 2 ZP 0.33 nmol/mol / RP 2.80 nmol/mol NO channel - CO_2 System 1 ZP 1.27 nmol/mol / RP -0.07 nmol/mol System 2 ZP 1.03 nmol/mol / RP -0.33 nmol/mol NO channel - NH_3 System 1 ZP 1.37 nmol/mol / RP 2.13 nmol/mol System 2 ZP 1.67 nmol/mol / RP 0.97 nmol/mol NO_2 channel - H_2O System 1 ZP 0.07 nmol/mol / RP 2.27 nmol/mol System 2 ZP 0.23 nmol/mol / RP 2.13 nmol/mol NO_2 channel - CO_2 System 1 ZP -0.07 nmol/mol / RP -0.57 nmol/mol System 2 ZP 0.07 nmol/mol / RP 0.37 nmol/mol NO_2 channel - NH_3 System 1 ZP 0.97 nmol/mol / RP 0.83 nmol/mol System 2 ZP 0.93 nmol/mol / RP 0.80 nmol/mol	yes	123
8.4.12 Averaging effect	≤ 7.0% of the measured value	E_{av} system 1: 0.5% NO E_{av} system 2: 3.8% NO E_{av} system 1: 3.4% NO_2 E_{av} system 2: 1.6% NO_2	yes	127
8.4.13 Difference sample/calibration port	≤ 1.0%	Not applicable	yes	131
8.4.3 Response time (rise)	≤ 180 s	t_r system 1: 28 s (NO) t_r system 2: 27 s (NO) t_r system 1: 34.5 s (NO_2) t_r system 2: 35.5 s (NO_2)	yes	87
8.4.3 Response time (fall)	≤ 180 s	t_f system 1: 28 s (NO) t_f system 2: 28 s (NO) t_f system 1: 36 s (NO_2) t_f system 2: 37.5 s (NO_2)	yes	87

Performance characteristic	Performance criterion	Test result	Satisfied	Page
8.4.3 Difference between the rise and fall response time	≤ 10 s	t_d Analyser 1: 0 s (NO) t_d analyser 2: -1s (NO) t_d analyser 1: -0.5s (NO_2) t_d analyser 2: -2s (NO_2)	yes	87
8.4.14 Converter efficiency	≥ 98%	E_{conv} Analyser 1: 99.8% E_{conv} Analyser 2: 99.6%	yes	132
8.4.15 Residence time	≤ 3.0 s	System 1 1.2 s System 2 1.2 s	yes	135
8.5.7 Availability of the analyser	> 90%	A_a Analyser 1: 100% A_a Analyser 2: 100%	yes	146
8.5.5 Reproducibility standard deviation under field conditions	≤ 5.0% of the average over a period of 3 months	$S_{r,f}$ Analyser 1: 3.41% NO_2 $S_{r,f}$ Analyser 2: 3.41% NO_2	yes	141
8.5.4 Long-term drift at zero point	≤ 5.0 nmol/mol	$C_{,z}$ Analyser 1: 0.39 nmol/mol NO $C_{,z}$ Analyser 2: 0.94 nmol/mol NO $C_{,z}$ Analyser 1: -0.61 nmol/mol NO_2 $C_{,z}$ Analyser 2: 0.53 nmol/mol NO_2	yes	136
8.5.4 Long-term drift at span level	≤ 5.0% of the upper limit of the certification range	$C_{,s}$ Analyser 1: max. 1.29% NO $C_{,s}$ Analyser 2: max. 0.89% NO $C_{,s}$ Analyser 1: max. 0.61% NO_2 $C_{,s}$ Analyser 2: max. 1.33% NO_2	yes	136
8.4.4 Short-term drift at zero	≤ 2.0 nmol/mol over 12 h	$D_{s,z}$ system 1: -0.53 nmol/mol (NO) $D_{s,z}$ system 2: -0.51 nmol/mol (NO) $D_{s,z}$ Analyser 1: 0.17 nmol/mol (NO_2) $D_{s,z}$ Analyser 2: 0.65 nmol/mol (NO_2)	yes	92
8.4.4 Short-term drift at span level	≤ 6.0 nmol/mol over 12 h	$D_{s,s}$ system 1: -1.69 nmol/mol (NO) $D_{s,s}$ system 2: -0.20 nmol/mol (NO) $D_{s,s}$ system 1: -2.08 nmol/mol (NO_2) $D_{s,s}$ Analyser 2: 0.98 nmol/mol (NO_2)	yes	92

Table 71: Expanded uncertainty from the laboratory test for NO, system 1

Measuring device:	M405nm					Serial-No.:	1073	
Measured component:	NO					1h-limit value:	104.6	nmol/mol
No.	**Performance characteristic**	**Performance criterion**		**Result**	**Partial uncertainty**		**Square of partial uncertainty**	
1	Repeatability standard deviation at zero	≤	1.0 nmol/mol	0.670	$u_{r,z}$	0.12	0.0140	
2	Repeatability standard deviation at 1h-limit value	≤	3.0 nmol/mol	1.070	$u_{r,lh}$	0.04	0.0015	
3	"lack of fit" at 1h-limit value	≤	4.0% of measured value	0.660	$u_{l,lh}$	0.40	0.1589	
4	Sensitivity coefficient of sample gas pressure at 1h-limit value	≤	8.0 nmol/mol/kPa	0.340	u_{gp}	0.86	0.7319	
5	Sensitivity coefficient of sample gas temperature at 1h-limit value	≤	3.0 nmol/mol/K	0.080	u_{gt}	0.20	0.0405	
6	Sensitivity coefficient of surrounding temperature at 1h-limit value	≤	3.0 nmol/mol/K	0.250	u_{st}	0.63	0.3957	
7	Sensitivity coefficient of electrical voltage at 1h-limit value	≤	0.30 nmol/mol/V	0.010	u_V	0.04	0.0015	
8a	Interferent H_20 with 19 mmol/mol	≤	10 nmol/mol (Zero)	1.870	u_{H2O}	1.47	2.1687	
		≤	10 nmol/mol (Span)	2.370				
8b	Interferent CO_2 with 500 µmol/mol	≤	5.0 nmol/mol (Zero)	1.270	$u_{int,pos}$ or $u_{int,neg}$	1.45	2.1166	
		≤	5.0 nmol/mol (Span)	-0.070				
8c	Interferent NH_3 mit 200 nmol/mol	≤	5.0 nmol/mol (Zero)	1.370				
		≤	5.0 nmol/mol (Span)	2.130				
9	Averaging effect	≤	7.0% of measured value	0.500	u_{av}	0.30	0.0912	
18	Difference sample/calibration port	≤	1.0%	0.000	$u_{\Delta sc}$	0.00	0.0000	
21	Converter efficiency	≥	98	99.80	u_{EC}	0.21	0.0438	
23	Uncertainty of test gas	≤	3.0%	2.000	u_{cg}	1.05	1.0941	
				Combined standard uncertainty	u_c		2.6218	nmol/mol
				Expanded uncertainty	U		5.2436	nmol/mol
				Relative expanded uncertainty	W		5.01	%
				Maximum allowed expanded uncertainty	W_{req}		15	%

Table 72: Expanded uncertainty from the results obtained in the laboratory and field tests for NO, system 1

Measuring device:	M405nm					Serial-No.:	1073	
Measured component:	NO					1h-limit value:	104.6	nmol/mol
No.	**Performance characteristic**	**Performance criterion**		**Result**	**Partial uncertainty**		**Square of partial uncertainty**	
1	Repeatability standard deviation at zero	≤	1.0 nmol/mol	0.670	$u_{r,z}$	0.12	0.0140	
2	Repeatability standard deviation at 1h-limit value	≤	3.0 nmol/mol	1.070	$u_{r,lh}$	not considered, as √2*ur,lh = 0,05 < ur,f	-	
3	"lack of fit" at 1h-limit value	≤	4.0% of measured value	0.660	$u_{l,lh}$	0.40	0.1589	
4	Sensitivity coefficient of sample gas pressure at 1h-limit value	≤	8.0 nmol/mol/kPa	0.340	u_{gp}	0.86	0.7319	
5	Sensitivity coefficient of sample gas temperature at 1h-limit value	≤	3.0 nmol/mol/K	0.080	u_{gt}	0.20	0.0405	
6	Sensitivity coefficient of surrounding temperature at 1h-limit value	≤	3.0 nmol/mol/K	0.250	u_{st}	0.63	0.3957	
7	Sensitivity coefficient of electrical voltage at 1h-limit value	≤	0.30 nmol/mol/V	0.010	u_V	0.04	0.0015	
8a	Interferent H_20 with 19 mmol/mol	≤	10 nmol/mol (Zero)	1.870	u_{H2O}	1.47	2.1687	
		≤	10 nmol/mol (Span)	2.370				
8b	Interferent CO_2 with 500 µmol/mol	≤	5.0 nmol/mol (Zero)	1.270	$u_{int,pos}$ or $u_{int,neg}$	1.45	2.1166	
		≤	5.0 nmol/mol (Span)	-0.070				
8c	Interferent NH_3 mit 200 nmol/mol	≤	5.0 nmol/mol (Zero)	1.370				
		≤	5.0 nmol/mol (Span)	2.130				
9	Averaging effect	≤	7.0% of measured value	0.500	u_{av}	0.30	0.0912	
10	Reproducibility standard deviation under field conditions	≤	5.0% of average over 3 months	3.410	$u_{r,f}$	3.57	12.7225	
11	Long term drift at zero level	≤	5.0 nmol/mol	0.390	$u_{d,l,z}$	0.23	0.0507	
12	Long term drift at span level	≤	5.0% of max. of certification range	1.290	$u_{d,l,lh}$	0.78	0.6069	
18	Difference sample/calibration port	≤	1.0%	0.000	$u_{\Delta sc}$	0.00	0.0000	
21	Converter efficiency	≥	98	99.800	u_{EC}	0.21	0.0438	
23	Uncertainty of test gas	≤	3.0%	2.000	u_{cg}	1.05	1.0941	
				Combined standard uncertainty	u_c		4.5001	nmol/mol
				Expanded uncertainty	U		9.0002	nmol/mol
				Relative expanded uncertainty	W		8.60	%
				Maximum allowed expanded uncertainty	W_{req}		15	%

Table 73: Expanded uncertainty from the laboratory test for NO, system 2

Measuring device:	M405nm					Serial-No.:	1076	
Measured component:	NO					1h-limit value:	104.6	nmol/mol
No.	**Performance characteristic**	**Performance criterion**		**Result**	**Partial uncertainty**		**Square of partial uncertainty**	
1	Repeatability standard deviation at zero	≤	1.0 nmol/mol	0.500	$u_{r,z}$	0.09	0.0076	
2	Repeatability standard deviation at 1h-limit value	≤	3.0 nmol/mol	1.030	$u_{r,lh}$	0.04	0.0014	
3	"lack of fit" at 1h-limit value	≤	4.0% of measured value	1.150	$u_{l,lh}$	0.69	0.4823	
4	Sensitivity coefficient of sample gas pressure at 1h-limit value	≤	8.0 nmol/mol/kPa	0.430	u_{gp}	1.08	1.1707	
5	Sensitivity coefficient of sample gas temperature at 1h-limit value	≤	3.0 nmol/mol/K	0.050	u_{gt}	0.13	0.0158	
6	Sensitivity coefficient of surrounding temperature at 1h-limit value	≤	3.0 nmol/mol/K	0.253	u_{st}	0.64	0.4053	
7	Sensitivity coefficient of electrical voltage at 1h-limit value	≤	0.30 nmol/mol/V	0.000	u_V	0.00	0.0000	
8a	Interferent H_20 with 19 mmol/mol	≤	10 nmol/mol (Zero)	0.330	u_{H2O}	0.63	0.3944	
		≤	10 nmol/mol (Span)	2.800				
8b	Interferent CO_2 with 500 µmol/mol	≤	5.0 nmol/mol (Zero)	1.030	$u_{int,pos}$ or $u_{int,neg}$	1.31	1.7227	
		≤	5.0 nmol/mol (Span)	-0.330				
8c	Interferent NH_3 mit 200 nmol/mol	≤	5.0 nmol/mol (Zero)	1.670				
		≤	5.0 nmol/mol (Span)	0.970				
9	Averaging effect	≤	7.0% of measured value	3.800	u_{av}	2.29	5.2663	
18	Difference sample/calibration port	≤	1.0%	0.000	$u_{\Delta sc}$	0.00	0.0000	
21	Converter efficiency	≥	98	99.60	u_{EC}	0.42	0.1751	
23	Uncertainty of test gas	≤	3.0%	2.000	u_{cg}	1.05	1.0941	
				Combined standard uncertainty	u_c		3.2779	nmol/mol
				Expanded uncertainty	U		6.5558	nmol/mol
				Relative expanded uncertainty	W		6.27	%
				Maximum allowed expanded uncertainty	W_{req}		15	%

Table 74: Expanded uncertainty from the results obtained in the laboratory and field tests for NO, system 2

Measuring device:	M405nm					Serial-No.:	1076	
Measured component:	NO					1h-limit value:	104.6	nmol/mol
No.	**Performance characteristic**	**Performance criterion**		**Result**	**Partial uncertainty**		**Square of partial uncertainty**	
1	Repeatability standard deviation at zero	≤	1.0 nmol/mol	0.500	$u_{r,z}$	0.09	0.0076	
2	Repeatability standard deviation at 1h-limit value	≤	3.0 nmol/mol	1.030	$u_{r,lh}$	not considered, as √2*ur,lh = 0,05 < ur,f	-	
3	"lack of fit" at 1h-limit value	≤	4.0% of measured value	1.150	$u_{l,lh}$	0.69	0.4823	
4	Sensitivity coefficient of sample gas pressure at 1h-limit value	≤	8.0 nmol/mol/kPa	0.430	u_{gp}	1.08	1.1707	
5	Sensitivity coefficient of sample gas temperature at 1h-limit value	≤	3.0 nmol/mol/K	0.050	u_{gt}	0.13	0.0158	
6	Sensitivity coefficient of surrounding temperature at 1h-limit value	≤	3.0 nmol/mol/K	0.253	u_{st}	0.64	0.4053	
7	Sensitivity coefficient of electrical voltage at 1h-limit value	≤	0.30 nmol/mol/V	0.000	u_V	0.00	0.0000	
8a	Interferent H_20 with 19 mmol/mol	≤	10 nmol/mol (Zero)	0.330	u_{H2O}	0.63	0.3944	
		≤	10 nmol/mol (Span)	2.800				
8b	Interferent CO_2 with 500 µmol/mol	≤	5.0 nmol/mol (Zero)	1.030	$u_{int,pos}$ or $u_{int,neg}$	1.31	1.7227	
		≤	5.0 nmol/mol (Span)	-0.330				
8c	Interferent NH_3 mit 200 nmol/mol	≤	5.0 nmol/mol (Zero)	1.670				
		≤	5.0 nmol/mol (Span)	0.970				
9	Averaging effect	≤	7.0% of measured value	3.800	u_{av}	2.29	5.2663	
10	Reproducibility standard deviation under field conditions	≤	5.0% of average over 3 months	3.410	$u_{r,f}$	3.57	12.7225	
11	Long term drift at zero level	≤	5.0 nmol/mol	0.940	$u_{d,l,z}$	0.54	0.2945	
12	Long term drift at span level	≤	5.0% of max. of certification range	0.890	$u_{d,l,lh}$	0.54	0.2889	
18	Difference sample/calibration port	≤	1.0%	0.000	$u_{\Delta sc}$	0.00	0.0000	
21	Converter efficiency	≥	98	99.600	u_{EC}	0.42	0.1751	
23	Uncertainty of test gas	≤	3.0%	2.000	u_{cg}	1.05	1.0941	
				Combined standard uncertainty	u_c		4.9039	nmol/mol
				Expanded uncertainty	U		9.8077	nmol/mol
				Relative expanded uncertainty	W		9.38	%
				Maximum allowed expanded uncertainty	W_{req}		15	%

Table 75: Expanded uncertainty from the laboratory test for NO_2, system 1

Measuring device:	M405nm	Serial-No.:	1073
Measured component:	NO2	1h-limit value:	104.6 nmol/mol

No.	Performance characteristic	Performance criterion		Result	Partial uncertainty		Square of partial uncertainty	
1	Repeatability standard deviation at zero	≤	1.0 nmol/mol	0.350	$u_{r,z}$	0.07	0.0048	
2	Repeatability standard deviation at 1h-limit value	≤	3.0 nmol/mol	0.880	$u_{r,lh}$	0.17	0.0303	
3	"lack of fit" at 1h-limit value	≤	4.0% of measured value	2.360	$u_{l,lh}$	1.43	2.0313	
4	Sensitivity coefficient of sample gas pressure at 1h-limit value	≤	8.0 nmol/mol/kPa	0.190	u_{gp}	1.91	3.6572	
5	Sensitivity coefficient of sample gas temperature at 1h-limit value	≤	3.0 nmol/mol/K	0.100	u_{gt}	0.91	0.8206	
6	Sensitivity coefficient of surrounding temperature at 1h-limit value	≤	3.0 nmol/mol/K	0.197	u_{st}	1.78	3.1846	
7	Sensitivity coefficient of electrical voltage at 1h-limit value	≤	0.30 nmol/mol/V	0.000	u_V	0.00	0.0000	
8a	Interferent H_20 with 19 mmol/mol	≤	10 nmol/mol (Zero)	0.070	u_{H2O}	1.69	2.8479	
		≤	10 nmol/mol (Span)	2.270				
8b	Interferent CO_2 with 500 µmol/mol	≤	5.0 nmol/mol (Zero)	-0.070	$u_{int,pos}$ or $u_{int,neg}$	0.48	0.2299	
		≤	5.0 nmol/mol (Span)	-0.570				
8c	Interferent NH_3 mit 200 nmol/mol	≤	5.0 nmol/mol (Zero)	0.970				
		≤	5.0 nmol/mol (Span)	0.830				
9	Averaging effect	≤	7.0% of measured value	3.400	u_{av}	2.05	4.2160	
18	Difference sample/calibration port	≤	1.0%	0.000	$u_{\Delta sc}$	0.00	0.0000	
21	Converter efficiency	≥	98	99.80	u_{EC}	0.21	0.0438	
23	Uncertainty of test gas	≤	3.0%	2.000	u_{cg}	1.05	1.0941	
			Combined standard uncertainty			u_c	4.2656	nmol/mol
			Expanded uncertainty			U	8.5313	nmol/mol
			Relative expanded uncertainty			W	8.16	%
			Maximum allowed expanded uncertainty			W_{req}	15	%

Table 76: Expanded uncertainty from the results obtained in the laboratory and field tests for NO_2, system 1

Measuring device:	M405nm	Serial-No.:	1073
Measured component:	NO2	1h-limit value:	104.6 nmol/mol

No.	Performance characteristic	Performance criterion		Result	Partial uncertainty		Square of partial uncertainty	
1	Repeatability standard deviation at zero	≤	1.0 nmol/mol	0.350	$u_{r,z}$	0.07	0.0048	
2	Repeatability standard deviation at 1h-limit value	≤	3.0 nmol/mol	0.880	$u_{r,lh}$	not considered, as √2*ur,lh = 0,24 < ur,f	-	
3	"lack of fit" at 1h-limit value	≤	4.0% of measured value	2.360	$u_{l,lh}$	1.43	2.0313	
4	Sensitivity coefficient of sample gas pressure at 1h-limit value	≤	8.0 nmol/mol/kPa	0.190	u_{gp}	1.91	3.6572	
5	Sensitivity coefficient of sample gas temperature at 1h-limit value	≤	3.0 nmol/mol/K	0.100	u_{gt}	0.91	0.8206	
6	Sensitivity coefficient of surrounding temperature at 1h-limit value	≤	3.0 nmol/mol/K	0.197	u_{st}	1.78	3.1846	
7	Sensitivity coefficient of electrical voltage at 1h-limit value	≤	0.30 nmol/mol/V	0.000	u_V	0.00	0.0000	
8a	Interferent H_20 with 19 mmol/mol	≤	10 nmol/mol (Zero)	0.070	u_{H2O}	1.69	2.8479	
		≤	10 nmol/mol (Span)	2.270				
8b	Interferent CO_2 with 500 µmol/mol	≤	5.0 nmol/mol (Zero)	-0.070	$u_{int,pos}$ or $u_{int,neg}$	0.48	0.2299	
		≤	5.0 nmol/mol (Span)	-0.570				
8c	Interferent NH_3 mit 200 nmol/mol	≤	5.0 nmol/mol (Zero)	0.970				
		≤	5.0 nmol/mol (Span)	0.830				
9	Averaging effect	≤	7.0% of measured value	3.400	u_{av}	2.05	4.2160	
10	Reproducibility standard deviation under field conditions	≤	5.0% of average over 3 months	3.410	$u_{r,f}$	3.57	12.7225	
11	Long term drift at zero level	≤	5.0 nmol/mol	-0.610	$u_{d,l,z}$	-0.35	0.1240	
12	Long term drift at span level	≤	5.0% of max. of certification range	0.610	$u_{d,l,lh}$	0.37	0.1357	
18	Difference sample/calibration port	≤	1.0%	0.000	$u_{\Delta sc}$	0.00	0.0000	
21	Converter efficiency	≥	98	99.800	u_{EC}	0.21	0.0438	
23	Uncertainty of test gas	≤	3.0%	2.000	u_{cg}	1.05	1.0941	
			Combined standard uncertainty			u_c	5.5783	nmol/mol
			Expanded uncertainty			U	11.1566	nmol/mol
			Relative expanded uncertainty			W	10.67	%
			Maximum allowed expanded uncertainty			W_{req}	15	%

Table 77: Expanded uncertainty from the laboratory test for NO$_2$, system 2

Measuring device: M405nm Serial-No.: 1076

Measured component: NO2 1h-limit value: 104.6 nmol/mol

No.	Performance characteristic	Performance criterion		Result	Partial uncertainty		Square of partial uncertainty	
1	Repeatability standard deviation at zero	≤	1.0 nmol/mol	0.570	$u_{r,z}$	0.12	0.0134	
2	Repeatability standard deviation at 1h-limit value	≤	3.0 nmol/mol	0.780	$u_{r,lh}$	0.16	0.0248	
3	"lack of fit" at 1h-limit value	≤	4.0% of measured value	3.290	$u_{l,lh}$	1.99	3.9476	
4	Sensitivity coefficient of sample gas pressure at 1h-limit value	≤	8.0 nmol/mol/kPa	0.170	u_{gp}	1.71	2.9278	
5	Sensitivity coefficient of sample gas temperature at 1h-limit value	≤	3.0 nmol/mol/K	0.100	u_{gt}	0.91	0.8206	
6	Sensitivity coefficient of surrounding temperature at 1h-limit value	≤	3.0 nmol/mol/K	0.206	u_{st}	1.87	3.4822	
7	Sensitivity coefficient of electrical voltage at 1h-limit value	≤	0.30 nmol/mol/V	0.020	u_V	0.28	0.0772	
8a	Interferent H$_2$0 with 19 mmol/mol	≤	10 nmol/mol (Zero)	0.230	u_{H2O}	1.58	2.5089	
		≤	10 nmol/mol (Span)	2.130				
8b	Interferent CO$_2$ with 500 µmol/mol	≤	5.0 nmol/mol (Zero)	0.070	$u_{int,pos}$ or $u_{int,neg}$	0.68	0.4558	
		≤	5.0 nmol/mol (Span)	0.370				
8c	Interferent NH$_3$ mit 200 nmol/mol	≤	5.0 nmol/mol (Zero)	0.930				
		≤	5.0 nmol/mol (Span)	0.800				
9	Averaging effect	≤	7.0% of measured value	1.600	u_{av}	0.97	0.9336	
18	Difference sample/calibration port	≤	1.0%	0.000	$u_{\Delta sc}$	0.00	0.0000	
21	Converter efficiency	≥	98	99.60	u_{EC}	0.42	0.1751	
23	Uncertainty of test gas	≤	3.0%	2.000	u_{cg}	1.05	1.0941	
					Combined standard uncertainty	u_c	4.0619	nmol/mol
					Expanded uncertainty	U	8.1239	nmol/mol
					Relative expanded uncertainty	W	7.77	%
					Maximum allowed expanded uncertainty	W_{req}	15	%

Table 78: Expanded uncertainty from the results obtained in the laboratory and field tests for NO$_2$, system 2

Measuring device: M405nm Serial-No.: 1076

Measured component: NO2 1h-limit value: 104.6 nmol/mol

No.	Performance characteristic	Performance criterion		Result	Partial uncertainty		Square of partial uncertainty	
1	Repeatability standard deviation at zero	≤	1.0 nmol/mol	0.570	$u_{r,z}$	0.12	0.0134	
2	Repeatability standard deviation at 1h-limit value	≤	3.0 nmol/mol	0.780	$u_{r,lh}$	not considered, as √2*ur,lh = 0,22 < ur,f	-	
3	"lack of fit" at 1h-limit value	≤	4.0% of measured value	3.290	$u_{l,lh}$	1.99	3.9476	
4	Sensitivity coefficient of sample gas pressure at 1h-limit value	≤	8.0 nmol/mol/kPa	0.170	u_{gp}	1.71	2.9278	
5	Sensitivity coefficient of sample gas temperature at 1h-limit value	≤	3.0 nmol/mol/K	0.100	u_{gt}	0.91	0.8206	
6	Sensitivity coefficient of surrounding temperature at 1h-limit value	≤	3.0 nmol/mol/K	0.206	u_{st}	1.87	3.4822	
7	Sensitivity coefficient of electrical voltage at 1h-limit value	≤	0.30 nmol/mol/V	0.020	u_V	0.28	0.0772	
8a	Interferent H$_2$0 with 19 mmol/mol	≤	10 nmol/mol (Zero)	0.230	u_{H2O}	1.58	2.5089	
		≤	10 nmol/mol (Span)	2.130				
8b	Interferent CO$_2$ with 500 µmol/mol	≤	5.0 nmol/mol (Zero)	0.070	$u_{int,pos}$ or $u_{int,neg}$	0.68	0.4558	
		≤	5.0 nmol/mol (Span)	0.370				
8c	Interferent NH$_3$ mit 200 nmol/mol	≤	5.0 nmol/mol (Zero)	0.930				
		≤	5.0 nmol/mol (Span)	0.800				
9	Averaging effect	≤	7.0% of measured value	1.600	u_{av}	0.97	0.9336	
10	Reproducibility standard deviation under field conditions	≤	5.0% of average over 3 months	3.410	$u_{r,f}$	3.57	12.7225	
11	Long term drift at zero level	≤	5.0 nmol/mol	0.530	$u_{d,l,z}$	0.31	0.0936	
12	Long term drift at span level	≤	5.0% of max. of certification range	1.330	$u_{d,l,lh}$	0.80	0.6451	
18	Difference sample/calibration port	≤	1.0%	0.000	$u_{\Delta sc}$	0.00	0.0000	
21	Converter efficiency	≥	98	99.600	u_{EC}	0.42	0.1751	
23	Uncertainty of test gas	≤	3.0%	2.000	u_{cg}	1.05	1.0941	
					Combined standard uncertainty	u_c	5.4691	nmol/mol
					Expanded uncertainty	U	10.9382	nmol/mol
					Relative expanded uncertainty	W	10.46	%
					Maximum allowed expanded uncertainty	W_{req}	15	%

7. Recommendations for use in practice

Work in the maintenance interval

The tested measuring systems require regular performance of the following tasks:

- Regular visual inspections/telemetric inspections
- Instrument status ok
- No error messages
- Replace the external Teflon filter at the sample gas inlet as required by measurement site conditions;
- Perform zero and reference checks using suitable test gas every two weeks in accordance with standard EN 14211;

Other than that, follow the manufacturer’s instructions indicated in the user manual.

Environmental Protection/Air Pollution Control

M. Schneid

Guido Baum

Dipl.-Ing. Martin Schneider

Dipl.-Ing. Guido Baum

Cologne, February 19th, 2019
936/21242468/A

8. Bibliography

[1] VDI 4202 part 1: Performance test, declaration of suitability, and certification of point-related measuring systems for gaseous air pollutants of April 2018

[2] European standard EN 14211 Ambient air - Standard method for the measurement of the concentration of nitrogen dioxide and nitrogen monoxide by chemiluminescence, August 2012

[3] Directive 2008/50/EG of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe.

[4] Guideline "Demonstration of Equivalence of Ambient Air Monitoring Methods", English version dated January 2010

9. Appendices

Annex 1:

Additional test criteria specified in the Guide to the Demonstration of Equivalence of Ambient Air Monitoring Methods

The field test in accordance with EN 14211 and VDI 4202-1 was performed in the period from July 23rd, 2018 to October 29th, 2018.

However, the field test set-up remained installed from June 2018 to January 2019. During this entire period, an additional performance-tested Horiba APNA 370 measuring system (S/N 43286610022) was operated along side the Model 405 nm monitors. The reference analyser was connected to the same sample line as the two tested instruments. As was the case for the tested instrument, the length of the sample line was approximately 2 m.

This system also served to perform additional tests in compliance with the Guide to the Demonstration of Equivalence of Ambient Air Monitoring Methods.

To this effect, four measurements of a duration of four weeks each and spread out over a six-months period were selected for the purpose of comparing the Model 405 nm systems to a performance-tested SRM system. The measurement periods were selected to allow for consideration of various ambient conditions (temperature, humidity, pressure, NO_2 concentrations) during the evaluation of the measuring system. This is why the periods August 2018, October 2018, December 2018 and January 2019 were evaluated for an assessment as required by the Guide to the Demonstration of Equivalence of Ambient Air Monitoring Methods.

The adjustment of the tested and the reference instruments was checked just before each of the assessed periods. Moreover, the converter efficiency of the Horiba APNA 370 was checked regularly and found to exceed 98% over the entire test period.

NO and NO_2 were evaluated separately.

7.1 Determination of between-instrument uncertainty u_{bs} [8.5.3.2]

Between-instrument uncertainty w_{bs} shall be determined in accordance with section 8.5.3.2 of the Guide to the Demonstration of Equivalence of Ambient Air Monitoring Methods.

7.2 Equipment

Not required for this performance criterion

7.3 Testing

The field test was performed at the field test site in Cologne in four different one-month periods (**August**, **October**, **December** and **January**). Different seasons as well as different test gas concentrations were taken into consideration.

7.4 Evaluation

Section 8.5.3.2 of the guideline “Demonstration of Equivalence of Ambient Air Monitoring Methods” states:

In-between uncertainty w_{bs} shall be ≤ 5%. As no additional reference value was indicated, the 1-hour limit value for NO_2 (200 µg/m³ = 104.6 ppb) (2008/50/EG) served as the reference value. Thus, between-instrument uncertainty shall not exceed 5.2 ppb for NO_2.

For component NO, the 1-hour limit value specified for NO (631.3 µg/m³ = 505 ppb) served as benchmark. Thus, the between-instrument uncertainty shall not exceed 25 ppb for NO.

A between-AMS uncertainty > 5.2 ppb or 25 ppb is an indication of unsuitable performance of one or both instruments, and equivalence should not be stated.

Between-instrument uncertainty is calculated separately for each month.

The between-instrument uncertainty u_{bs} is calculated from the differences of all 1-hour averages of the instruments which are operated simultaneously as:

$$w_{bs}^2 = \frac{\sum_{i=1}^{n}(y_{i,1} - y_{i,2})^2}{2n\bar{y}^2}$$

Where: $y_{i,1}$ and $y_{i,2}$ = Results of the parallel measurements of individual 1h-values i

n = Number of 1h values

7.5 Assessment

Between-instrument uncertainty w_{bs} did not exceed 1.440 ppb for NO and 1.846 ppb for NO_2 and thus remained below the specified maximum.

Criterion satisfied? yes

7.6 Detailed presentation of test results

Table 79 and Table 80 list the calculated values for the between-AMS uncertainties u_{bs}. A corresponding chart is provided in Figure 15 to Figure 22.

Table 79: Between-AMS uncertainty w_{bs} component NO

Tested instruments	**Measurement month**	**Number of measurements**	**Uncertainty w_{bs}**
Component NO			
SN 1073 / SN 1076	August	744	0.271
SN 1073 / SN 1076	October	744	0.117
SN 1073 / SN 1076	December	744	0.077
SN 1073 / SN 1076	January	744	0.060

Table 80: Between-AMS uncertainty w_{bs} component NO_2

Tested instruments	**Measurement month**	**Number of measurements**	**Uncertainty w_{bs}**
Component NO_2			
SN 1073 / SN 1076	August	744	0.057
SN 1073 / SN 1076	October	744	0.028
SN 1073 / SN 1076	December	744	0.089
SN 1073 / SN 1076	January	744	0.095

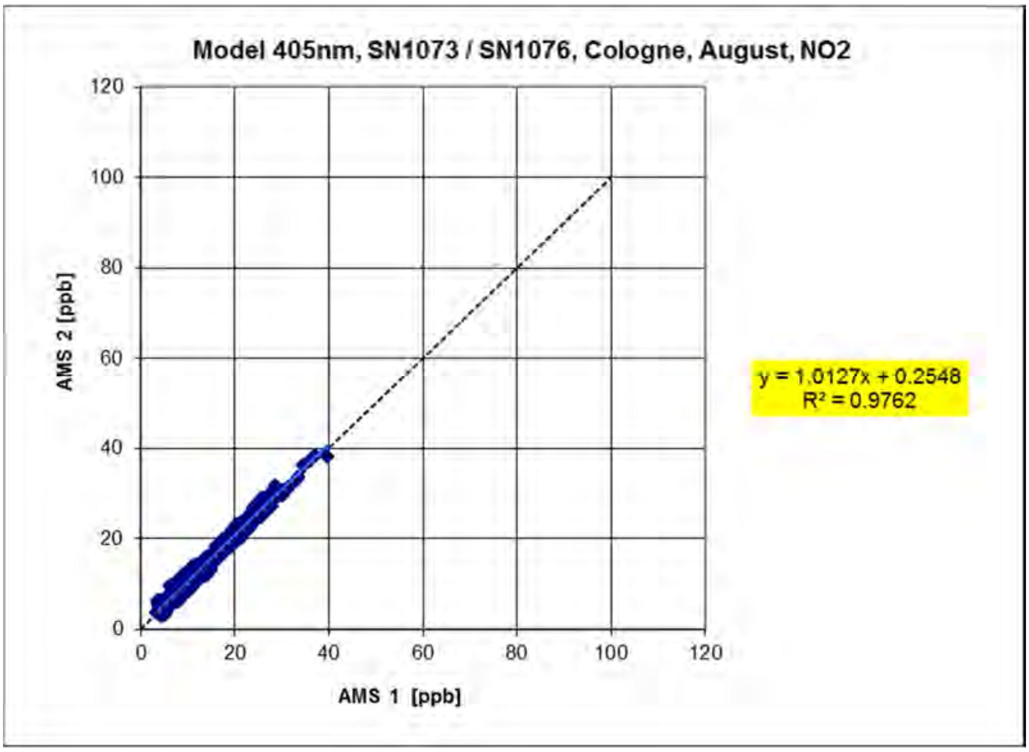


Figure 15: Results of parallel measurements with the tested instruments, August, component NO_2

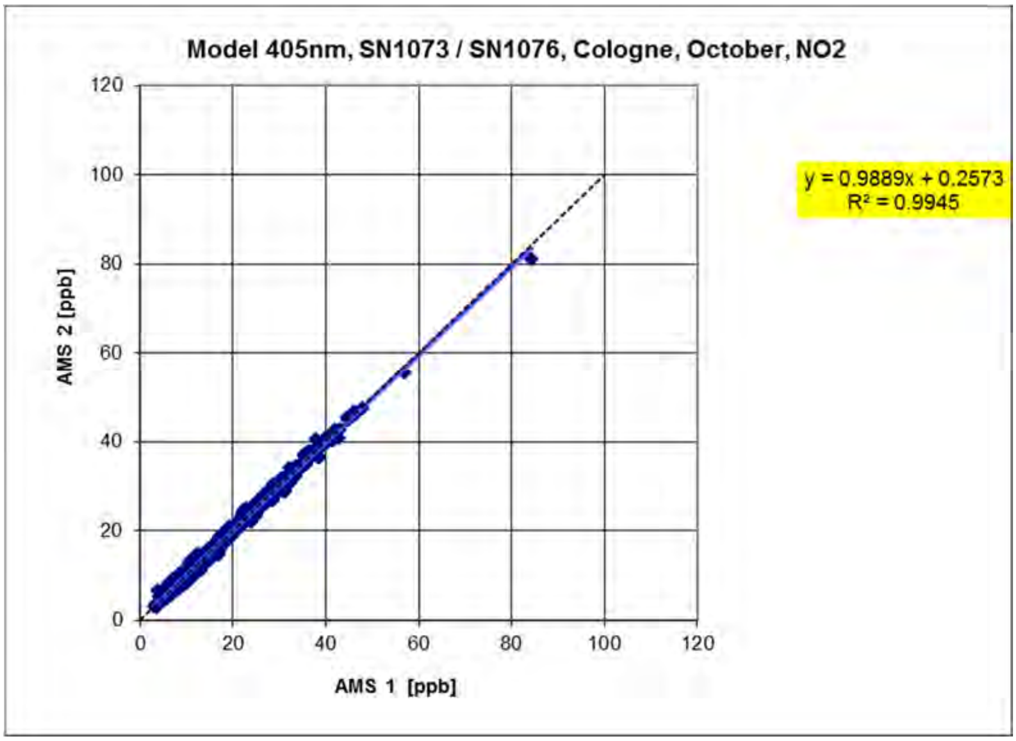


Figure 16: Results of parallel measurements with the tested instruments, October, component NO_2

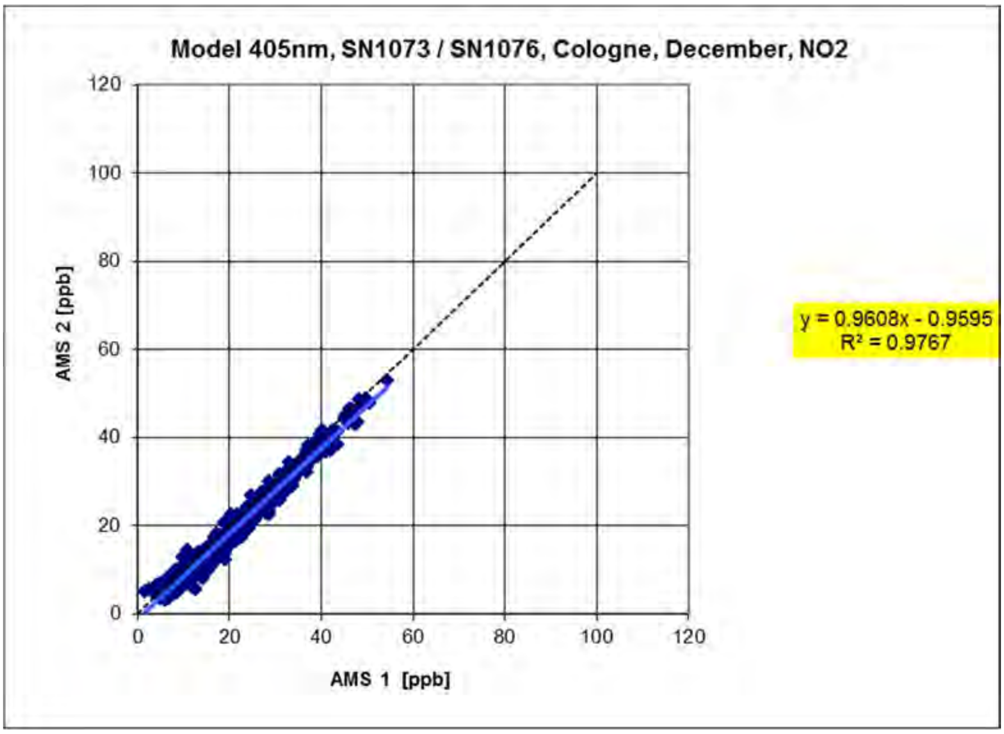


Figure 17: Results of parallel measurements with the tested instruments, December, component NO_2

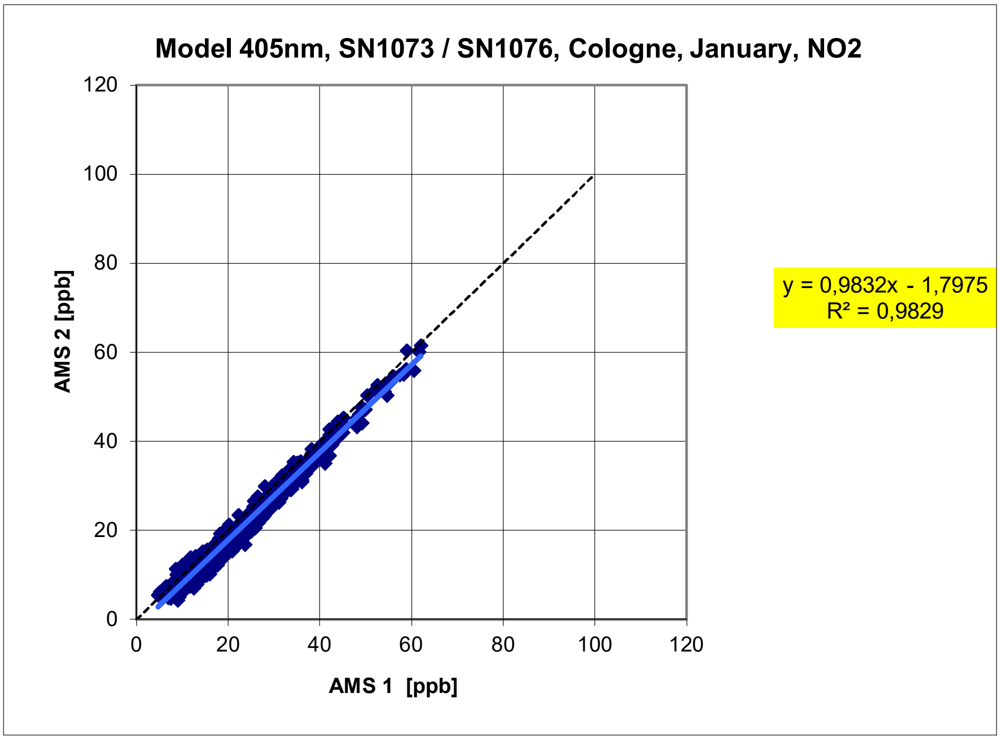


Figure 18: Results of parallel measurements with the tested instruments, January, component NO_2

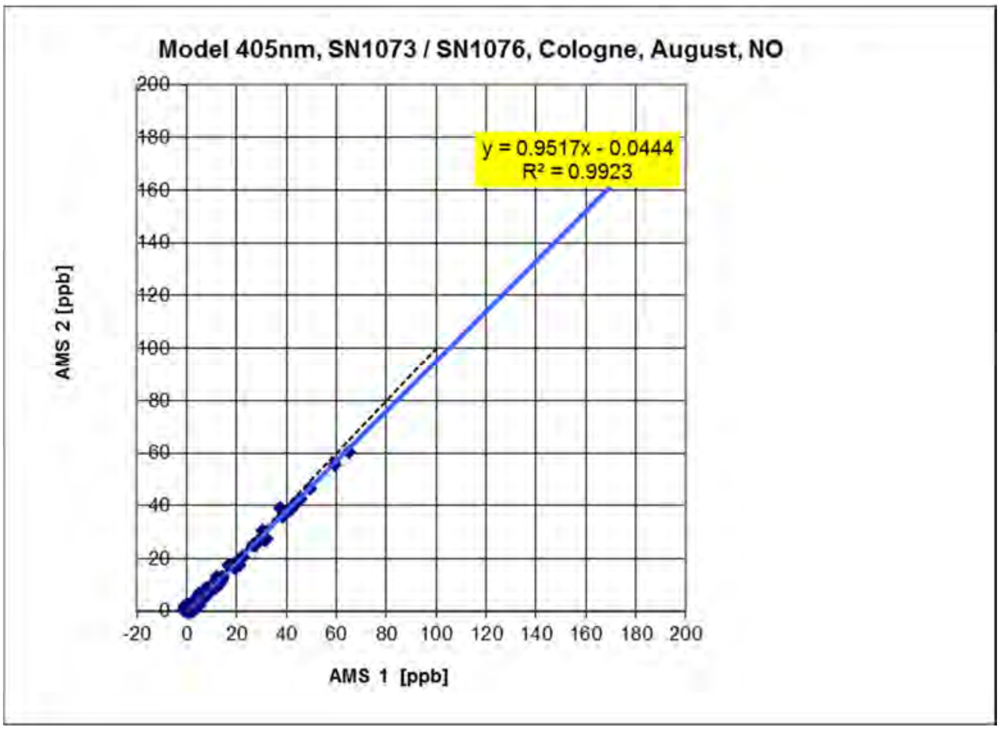


Figure 19: Results of parallel measurements with the tested instruments, August, component NO

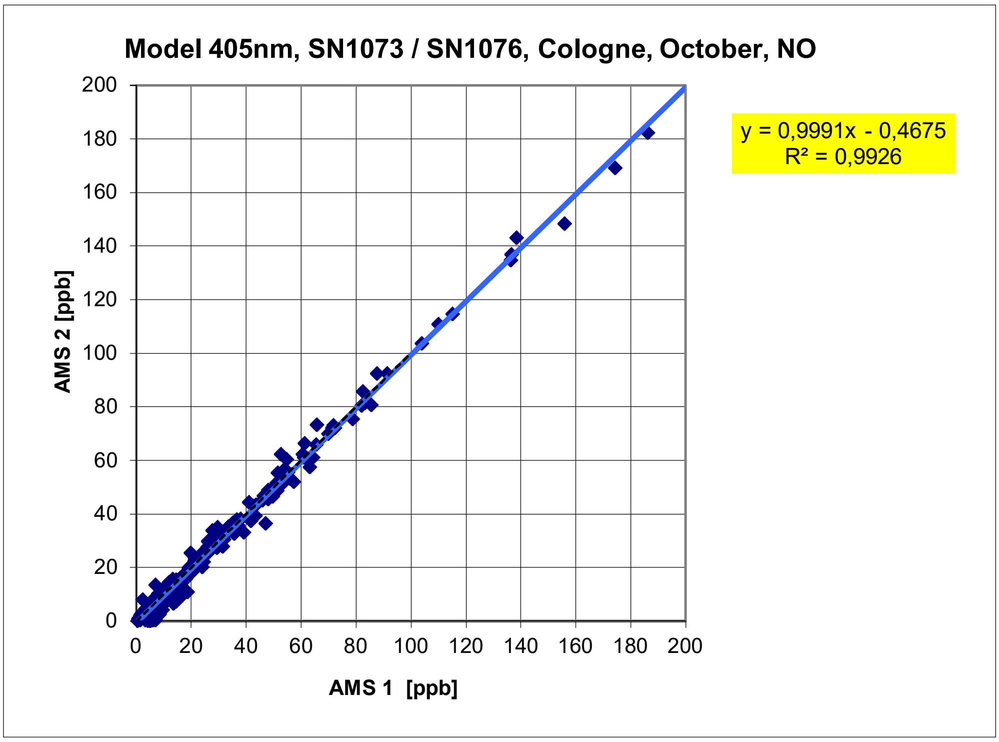


Figure 20: Results of parallel measurements with the tested instruments, October, component NO

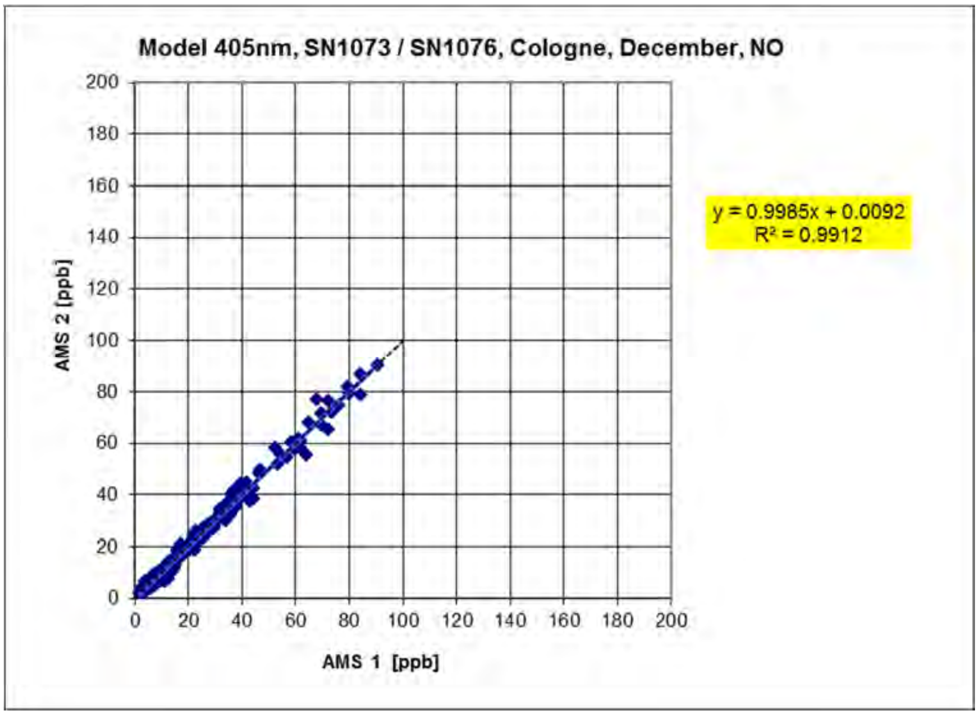


Figure 21: Results of parallel measurements with the tested instruments, December, component NO

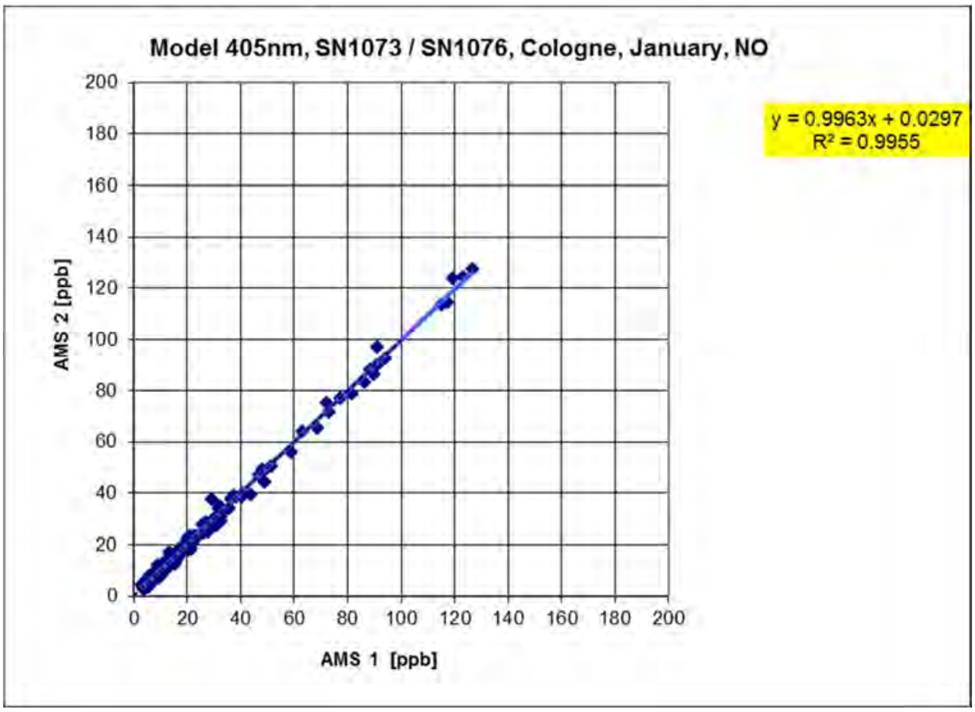


Figure 22: Results of parallel measurements with the tested instruments, January, component NO

7.1 Comparison with the standard reference method [8.5.3.3]

Equivalence with the reference method shall be demonstrated for the candidates in accordance with section 8.5.3.3 of the Guide to the Demonstration of Equivalence of Ambient Air Monitoring Methods. The highest resulting uncertainty estimate for both candidate instruments shall be compared with the data quality objective specified by the EU Directive [3].

7.2 Equipment

Additional equipment as described in chapter 4 of this report was used for this test.

7.3 Testing

The field test was performed at the field test site in Cologne in four different one-month periods (August, October, December and January). Different seasons as well as different test gas concentrations were taken into consideration.

Four measurements were performed over a period of one month each. Measurements were spread out over 6 months. The concentrations measured were related to the ambient conditions.

7.4 Evaluation

In order to assess comparability of the tested instruments y with the reference method x, a linear relationship $y_i = a + bx_i$ between the measured values of both methods is assumed. The association between the means of the reference systems and the candidate instruments is established by means of orthogonal regression.

For the assessment, the uncertainty w_{c_s} resulting from a comparison of the test specimens with the reference method is described in the following equation which defines w_{c_s} as a function of the sample gas concentration x_i.

$$w_{c\_s}^2(y_i) = \frac{RSS}{(n-2)} - u^2(x_i) + \left[a + (b-1)x_i\right]^2$$

Where RSS is the sum of the (relative) residuals from orthogonal regression

$u(x_i)$ = is the random uncertainty of the results of the reference method.

The algorithms for calculating axis intercept a and slope b as well as their variance by means of orthogonal regression are described in detail in the annex to [4].

The sum of (relative) residuals RSS is calculated according to the following equation:

$$\mathrm{RSS} = \sum_{i=1}^{n} (y_i - a - bx_i)^2$$

[8.5.3] For all datasets the combined relative uncertainty of the instrument $w_{c,CM}$ is calculated from a combination of contributions from 8.5.3.1 and 8.5.3.2 in accordance with the following equation:

$$w_{c,CM}^2(y_i) = \frac{u_{c\_s}^2(y_i)}{y_i^2}$$

For each dataset, the uncertainty $w_{c,CM}$ is computed at the 1-hour limit value for NO_2 (here: 200 µg/m³ = 104.6 ppb) with y_i being used as the concentration at the limit value. For NO, the uncertainty is related to the 1-hour limit value (631.3 µg/m³ = 505 ppb).

[Item 8.5.3.4] For each dataset the expanded relative uncertainty of the results measured with the test specimen is calculated by multiplying $w_{c,CM}$ by an coverage factor k according to the following equation:

$$W_{CM} = k \cdot w_{CM}$$

In practice, k is specified at k=2 for large n.

The largest resulting uncertainty W_{CM} is compared and assessed against the criteria for data quality of air quality measurements in accordance with EU Directive. The specified expanded relative uncertainty W_{cm} is at 15% for NO_2 and NO.

7.5 Assessment

The uncertainty W_{CM} determined without applying correction factors for all observed data sets is below the determined expanded relative uncertainty W_{cm} of 15% for fine particulate matter.

Criterion satisfied? yes

7.6 Detailed presentation of test results

Table 81 and Table 82 summarise the assessment of the expanded uncertainties W_{CM} obtained from the field test. Table 83 to Table 90 show the results of evaluating individual data sets.

Table 81: Summary and evaluation of the expanded uncertainty W_{CM} from the field test for NO_2.

Month	**Component**	**Limit value** ppb	**Slope b** (ppb)/(ppb)	**Axis intercept a** ppb	**u_{c_s} at the limit value** ppb	**S** %	**S** %	**$W_{CM} \leq W_{dqo}$** (W_{dqo} = 15%)
August	NO_2	104.6	1.02	-0.25	2.30	2.20	4.41	yes
October	NO_2	104.6	0.98	1.65	1.82	1.74	3.48	yes
December	NO_2	104.6	0.96	1.84	2.99	2.86	5.72	yes
January	NO_2	104.6	1.03	-1.50	2.58	2.46	4.93	yes

Table 82: Summary and evaluation of the expanded uncertainty W_{CM} from the field test for NO.

Month	**Component**	**Limit value** ppb	**Slope b** (ppb)/(ppb)	**Axis intercept a** ppb	**u_{c_s} at the limit value** ppb	**S** %	**S** %	**$W_{CM} \leq W_{dqo}$** (W_{dqo} = 15%)
August	NO	505	0.98	0.33	8.24	1.63	3.26	yes
October	NO	505	0.96	2.64	16.73	3.31	6.63	yes
December	NO	505	0.97	3.63	14.04	2.78	5.56	yes
January	NO	505	1.03	-2.27	14.94	2.96	5.92	yes

Table 83: Comparison of the tested and the reference instrument, August, component NO_2

Comparison candidate with refernce according to guidance "Demonstration of Equivalence Of Ambient Air Monitoring Methods"				
Device	Model 405nm	SN	SN1073 / SN1076	
Testside / month	Cologne, August	Limit value	104.6	ppb
Component	NO2	allowed uncertainty	15	%
Results of the regression analysis				
Slope b	**1.02**	**significant**		
Uncertainty of b	**0.01**			
Ordinate intercept a	**-0.25**	**significant**		
Uncertainty of a	**0.09**			
Results of the equivalence test				
Deviation at limit value	**2.09**	**µg/m³**		
Uncertainty u_{c_s} at limit value	**2.30**	**µg/m³**		
Combined measurement uncertainty w_{CM}	**2.20**	**%**		
Expanded uncertainty W_{CM}	**4.41**	**%**		
Status equivalence test	**passed**			

Table 84: Comparison of the tested and the reference instrument, October, component NO_2

Comparison candidate with refernce according to guidance "Demonstration of Equivalence Of Ambient Air Monitoring Methods"				
Device	Model 405nm	SN	SN1073 / SN1076	
Testside / month	Cologne, October	Limit value	104.6	ppb
Component	NO2	allowed uncertainty	15	%
Results of the regression analysis				
Slope b	**0.98**	**significant**		
Uncertainty of b	**0.01**			
Ordinate intercept a	**1.65**	**significant**		
Uncertainty of a	**0.13**			
Results of the equivalence test				
Deviation at limit value	**0.07**	**µg/m³**		
Uncertainty u_{c_s} at limit value	**1.82**	**µg/m³**		
Combined measurement uncertainty w_{CM}	**1.74**	**%**		
Expanded uncertainty W_{CM}	**3.48**	**%**		
Status equivalence test	**passed**			

Table 85: Comparison of the tested and the reference instrument, December, component NO$_2$

Comparison candidate with refernce according to guidance "Demonstration of Equivalence Of Ambient Air Monitoring Methods"				
Device	Model 405nm	SN	SN1073 / SN1076	
Testside / month	Cologne, December	Limit value	104.6	ppb
Component	NO2	allowed uncertainty	15	%
Results of the regression analysis				
Slope b	**0.96**	**significant**		
Uncertainty of b	**0.00**			
Ordinate intercept a	**1.84**	**significant**		
Uncertainty of a	**0.08**			
Results of the equivalence test				
Deviation at limit value	**-2.75**	**$\mu g/m^3$**		
Uncertainty u_{c_s} at limit value	**2.99**	**$\mu g/m^3$**		
Combined measurement uncertainty w_{CM}	**2.86**	**%**		
Expanded uncertainty W_{CM}	**5.72**	**%**		
Status equivalence test	**passed**			

Table 86: Comparison of the tested and the reference instrument, January, component NO$_2$

Comparison candidate with refernce according to guidance "Demonstration of Equivalence Of Ambient Air Monitoring Methods"				
Device	Model 405nm	SN	SN1073 / SN1076	
Testside / month	Cologne, January	Limit value	104.6	ppb
Component	NO2	allowed uncertainty	15	%
Results of the regression analysis				
Slope b	**1.03**	**significant**		
Uncertainty of b	**0.01**			
Ordinate intercept a	**-1.50**	**significant**		
Uncertainty of a	**0.15**			
Results of the equivalence test				
Deviation at limit value	**1.68**	**$\mu g/m^3$**		
Uncertainty u_{c_s} at limit value	**2.58**	**$\mu g/m^3$**		
Combined measurement uncertainty w_{CM}	**2.46**	**%**		
Expanded uncertainty W_{CM}	**4.93**	**%**		
Status equivalence test	**passed**			

Table 87: Comparison of the tested and the reference instrument, August, component NO

Comparison candidate with refernce according to guidance "Demonstration of Equivalence Of Ambient Air Monitoring Methods"				
Device	Model 405nm	SN	SN1073 / SN1076	
Testside / month	Cologne, August	Limit value	505	ppb
Component	NO	allowed uncertainty	15	%
Results of the regression analysis				
Slope b	**0.98**	**significant**		
Uncertainty of b	**0.00**			
Ordinate intercept a	**0.33**	**significant**		
Uncertainty of a	**0.04**			
Results of the equivalence test				
Deviation at limit value	**-8.19**	**µg/m³**		
Uncertainty u_{c_s} at limit value	**8.24**	**µg/m³**		
Combined measurement uncertainty w_{CM}	**1.63**	**%**		
Expanded uncertainty W_{CM}	**3.26**	**%**		
Status equivalence test	**passed**			

Table 88: Comparison of the tested and the reference instrument, October, component NO

Comparison candidate with refernce according to guidance "Demonstration of Equivalence Of Ambient Air Monitoring Methods"				
Device	Model 405nm	SN	SN1073 / SN1076	
Testside / month	Cologne, October	Limit value	505	ppb
Component	NO	allowed uncertainty	15	%
Results of the regression analysis				
Slope b	**0.96**	**significant**		
Uncertainty of b	**0.00**			
Ordinate intercept a	**2.64**	**significant**		
Uncertainty of a	**0.08**			
Results of the equivalence test				
Deviation at limit value	**-16.60**	**µg/m³**		
Uncertainty u_{c_s} at limit value	**16.73**	**µg/m³**		
Combined measurement uncertainty w_{CM}	**3.31**	**%**		
Expanded uncertainty W_{CM}	**6.63**	**%**		
Status equivalence test	**passed**			

Table 89: Comparison of the tested and the reference instrument, December, component NO

Comparison candidate with refernce according to guidance "Demonstration of Equivalence Of Ambient Air Monitoring Methods"				
Device	Model 405nm	SN	SN1073 / SN1076	
Testside / month	Cologne, December	Limit value	505	ppb
Component	NO	allowed uncertainty	15	%
Results of the regression analysis				
Slope b	**0.97**	**significant**		
Uncertainty of b	**0.01**			
Ordinate intercept a	**3.63**	**significant**		
Uncertainty of a	**0.11**			
Results of the equivalence test				
Deviation at limit value	**-13.77**	**µg/m³**		
Uncertainty u_{c_s} at limit value	**14.04**	**µg/m³**		
Combined measurement uncertainty w_{CM}	**2.78**	**%**		
Expanded uncertainty W_{CM}	**5.56**	**%**		
Status equivalence test	**passed**			

Table 90: Comparison of the tested and the reference instrument, January, component NO

Comparison candidate with refernce according to guidance "Demonstration of Equivalence Of Ambient Air Monitoring Methods"				
Device	Model 405nm	SN	SN1073 / SN1076	
Testside / month	Cologne, January	Limit value	505	ppb
Component	NO	allowed uncertainty	15	%
Results of the regression analysis				
Slope b	**1.03**	**significant**		
Uncertainty of b	**0.00**			
Ordinate intercept a	**-2.27**	**significant**		
Uncertainty of a	**0.07**			
Results of the equivalence test				
Deviation at limit value	**14.87**	**µg/m³**		
Uncertainty u_{c_s} at limit value	**14.94**	**µg/m³**		
Combined measurement uncertainty w_{CM}	**2.96**	**%**		
Expanded uncertainty W_{CM}	**5.92**	**%**		
Status equivalence test	**passed**			

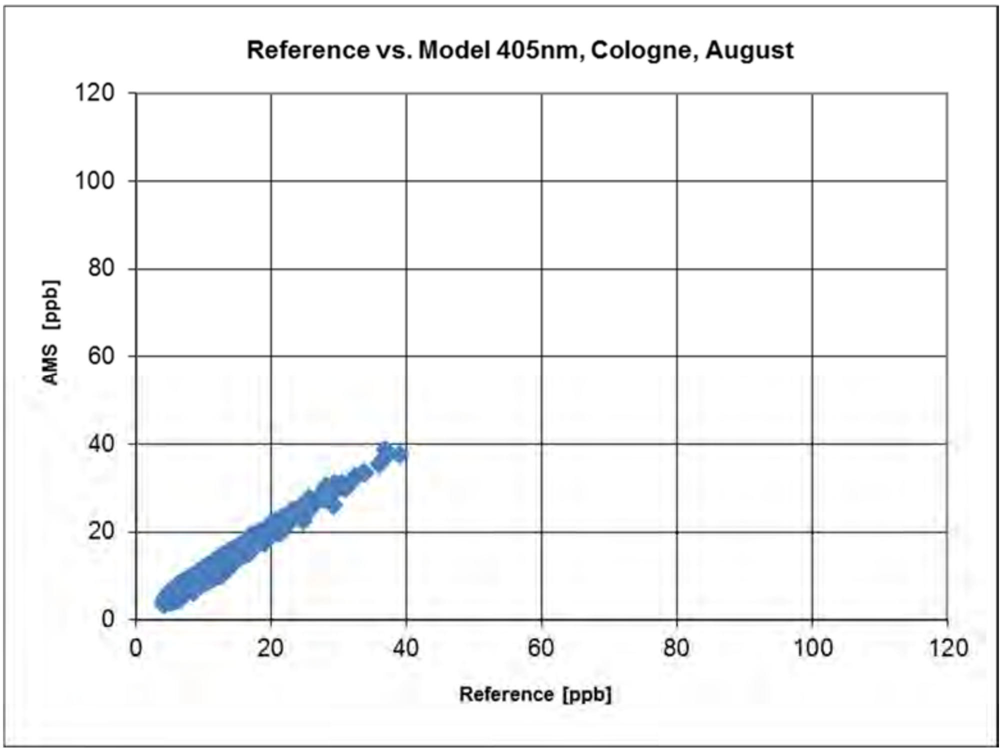


Figure 23: Reference vs. Tested instrument, month August, component NO_2

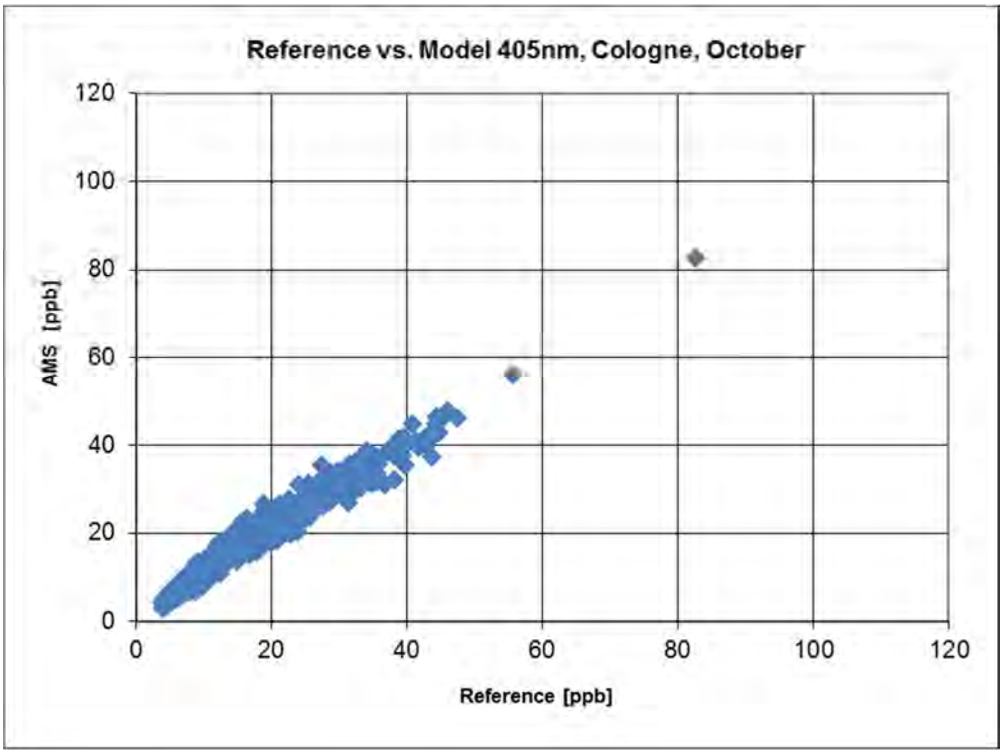


Figure 24: Reference vs. Tested instrument, month October, component NO_2

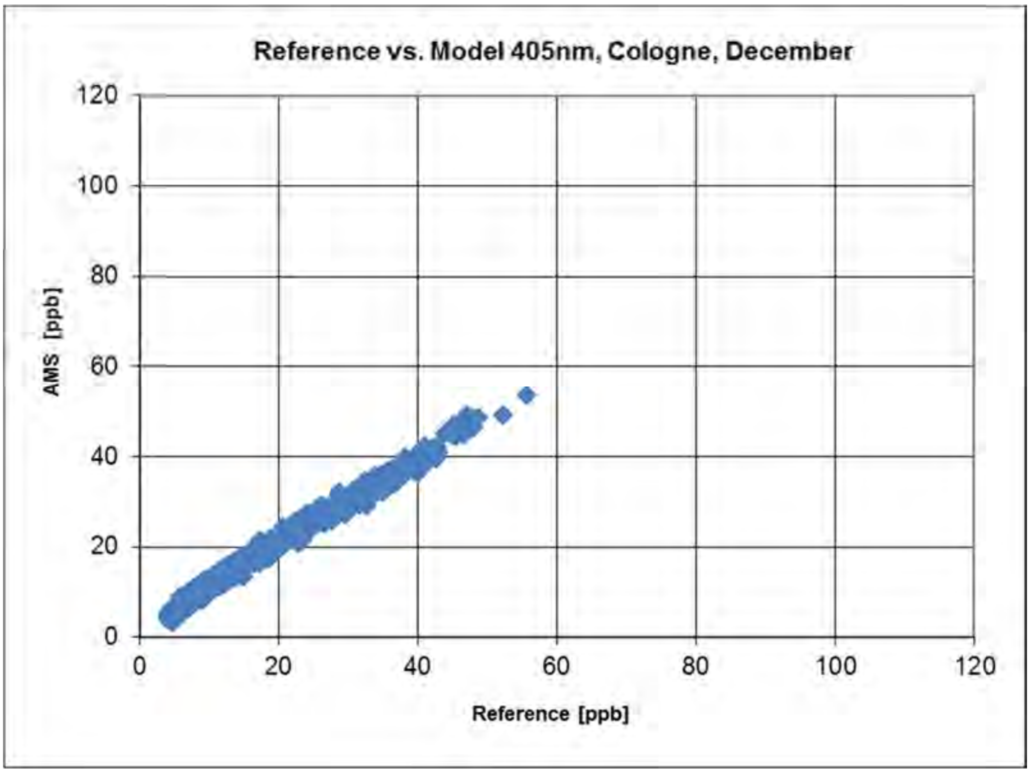


Figure 25: Reference vs. Tested instrument, month December, component NO_2

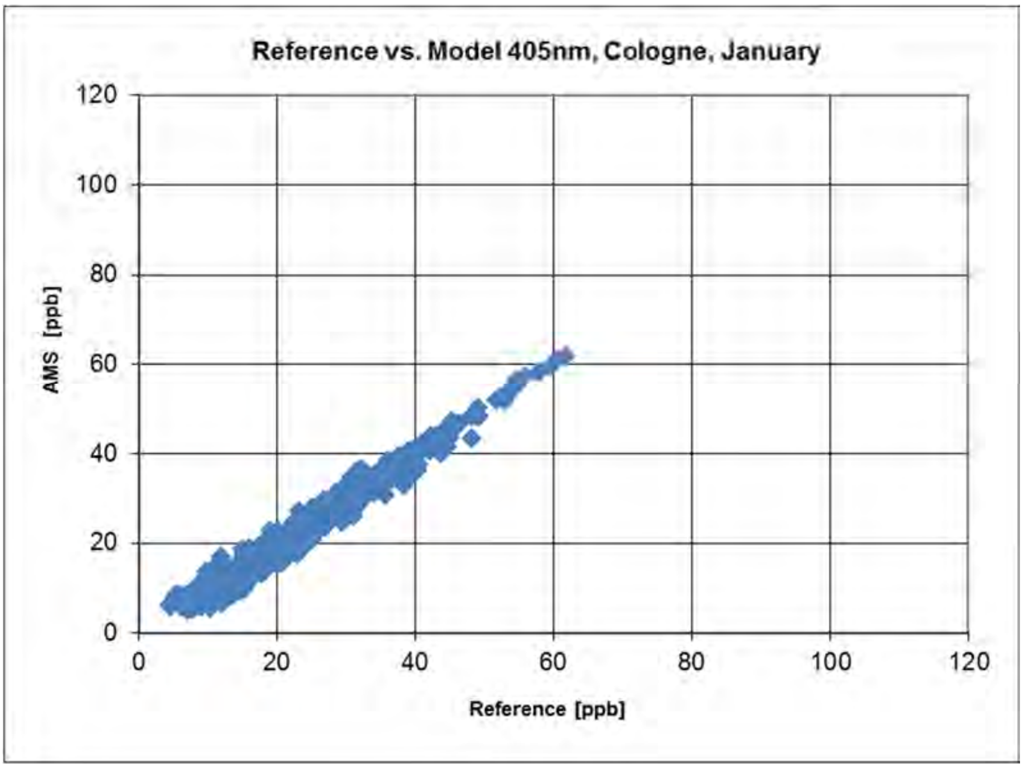


Figure 26: Reference vs. Tested instrument, month January, component NO_2

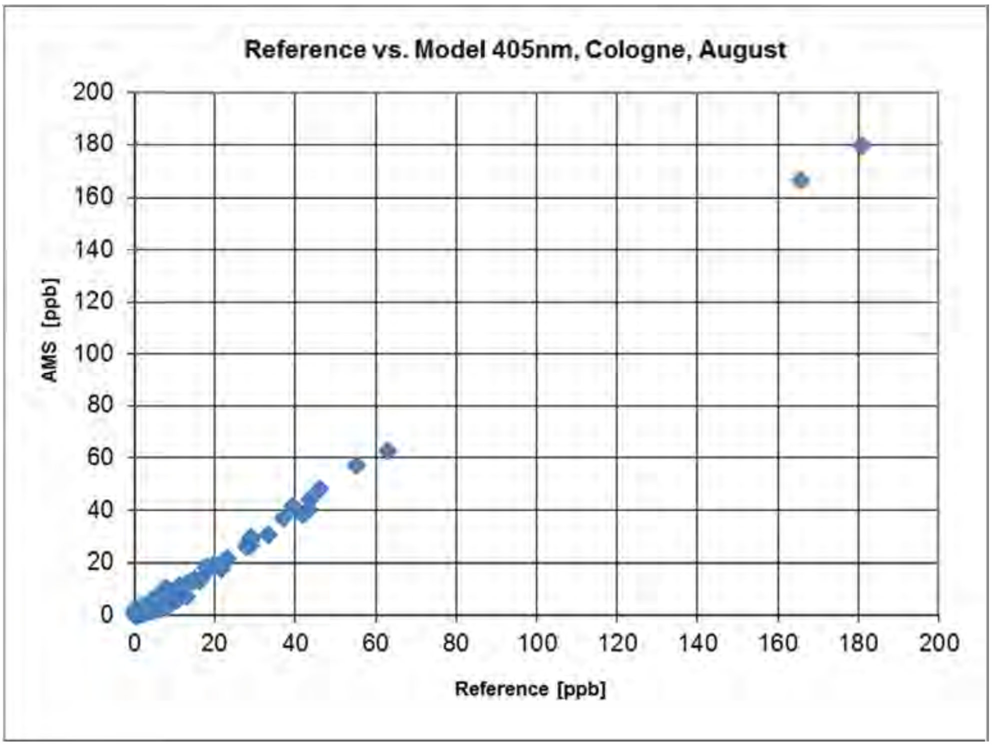


Figure 27: Reference vs. Tested instrument, month August, component NO

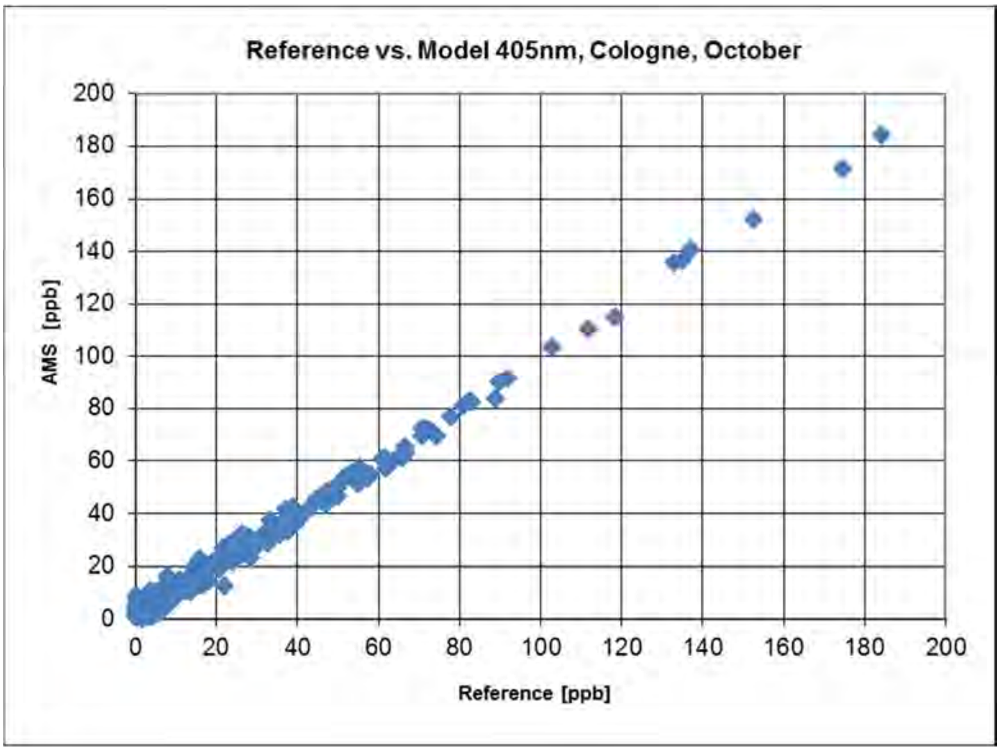


Figure 28: Reference vs. Tested instrument, month October, component NO

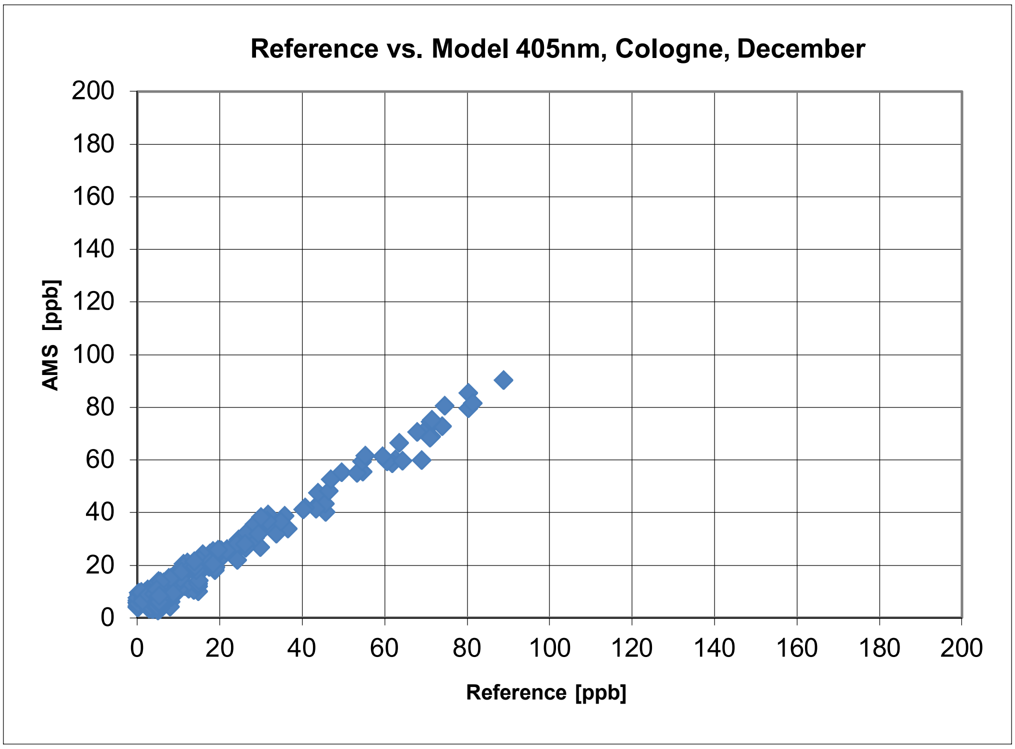


Figure 29: Reference vs. Tested instrument, month December, component NO

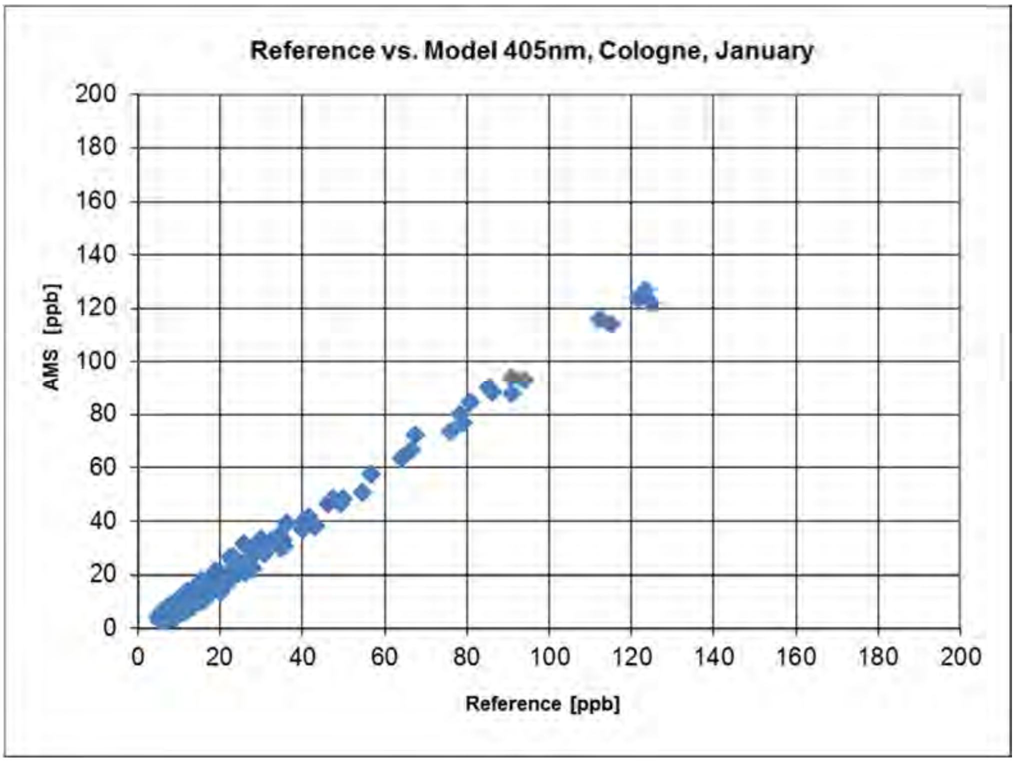


Figure 30: Reference vs. Tested instrument, month January, component NO

Table 91: Meteorological data (daily averages), August 2018

August 2018	date	avg. ambient temperature [°C]	rel. humidity [%]	pressure [hPa]
1	01.08.2018	27.1	55.7	1013.4
2	02.08.2018	29.2	55.3	1014.9
3	03.08.2018	31.6	44.8	1013.5
4	04.08.2018	30.3	45.6	1011.3
5	05.08.2018	26.1	58.7	1014.4
6	06.08.2018	28.8	44.3	1008.6
7	07.08.2018	31.7	39.2	1001.5
8	08.08.2018	27.1	57.5	1004.0
9	09.08.2018	24.4	65.8	1004.6
10	10.08.2018	22.5	50.5	1014.2
11	11.08.2018	21.1	52.9	1015.3
12	12.08.2018	23.4	49.9	1008.5
13	13.08.2018	20.9	76.7	1000.1
14	14.08.2018	21.6	80.9	1006.8
15	15.08.2018	23.3	67.5	1012.4
16	16.08.2018	25.1	65.0	1009.0
17	17.08.2018	21.6	74.6	1010.4
18	18.08.2018	22.8	59.7	1015.4
19	19.08.2018	24.3	62.3	1014.1
20	20.08.2018	23.5	74.6	1013.0
21	21.08.2018	26.1	63.7	1013.2
22	22.08.2018	26.6	60.9	1009.5
23	23.08.2018	25.4	67.5	1005.8
24	24.08.2018	20.5	63.5	1004.6
25	25.08.2018	16.7	72.3	1004.5
26	26.08.2018	18.2	61.4	1008.5
27	27.08.2018	20.4	66.8	1005.0
28	28.08.2018	21.7	63.6	1011.6
29	29.08.2018	22.1	70.9	1005.6
30	30.08.2018	18.9	74.1	1012.9
31	31.08.2018	18.0	68.4	1015.3

Table 92: Weather data (daily averages), October 2018

October 2018	date	avg. ambient temperature [°C]	rel. humidity [%]	pressure [hPa]
1	01.10.2018	12.9	68.8	1010.6
2	02.10.2018	12.2	82.7	1011.1
3	03.10.2018	12.1	92.8	1012.6
4	04.10.2018	14.9	83.6	1017.6
5	05.10.2018	13.4	89.1	1020.3
6	06.10.2018	16.1	77.5	1011.7
7	07.10.2018	19.1	75.3	1001.8
8	08.10.2018	15.0	83.3	1009.4
9	09.10.2018	13.5	81.7	1015.0
10	10.10.2018	16.2	84.1	1014.6
11	11.10.2018	18.8	77.6	1010.0
12	12.10.2018	19.4	75.2	1005.3
13	13.10.2018	21.4	72.2	1011.8
14	14.10.2018	22.1	66.4	1011.7
15	15.10.2018	21.4	62.8	1003.1
16	16.10.2018	20.9	64.0	1005.1
17	17.10.2018	19.2	74.8	1011.0
18	18.10.2018	19.1	76.0	1011.7
19	19.10.2018	16.4	89.1	1015.8
20	20.10.2018	14.0	89.2	1017.8
21	21.10.2018	12.7	83.7	1023.6
22	22.10.2018	11.6	81.9	1022.4
23	23.10.2018	11.4	89.3	1023.9
24	24.10.2018	12.0	84.4	1020.0
25	25.10.2018	15.3	95.4	1016.4
26	26.10.2018	14.3	86.5	1012.4
27	27.10.2018	12.2	83.2	1001.5
28	28.10.2018	8.2	94.3	1000.2
29	29.10.2018	7.2	86.1	1004.9
30	30.10.2018	7.8	90.1	993.6
31	31.10.2018	8.0	95.2	981.2

Table 93: Weather data (daily averages), December 2018

December 2018	date	avg. ambient temperature [°C]	rel. humidity [%]	pressure [hPa]
1	01.12.2018	10.5	92.3	1003.0
2	02.12.2018	9.7	91.4	1003.5
3	03.12.2018	13.8	93.5	992.0
4	04.12.2018	14.4	94.5	992.0
5	05.12.2018	8.7	95.1	1010.6
6	06.12.2018	6.8	92.4	1011.5
7	07.12.2018	5.2	91.7	1004.6
8	08.12.2018	5.7	96.2	1008.6
9	09.12.2018	6.9	91.4	1001.1
10	10.12.2018	8.1	88.9	1012.5
11	11.12.2018	6.0	96.6	1014.9
12	12.12.2018	4.9	93.6	1015.8
13	13.12.2018	3.7	83.4	1011.4
14	14.12.2018	3.0	73.7	1013.3
15	15.12.2018	2.1	74.9	1013.7
16	16.12.2018	1.7	96.8	1001.9
17	17.12.2018	6.1	95.4	1009.7
18	18.12.2018	6.1	95.7	1012.5
19	19.12.2018	9.5	86.6	1003.1
20	20.12.2018	9.6	90.3	1003.4
21	21.12.2018	12.6	84.6	996.3
22	22.12.2018	12.1	87.7	1004.8
23	23.12.2018	9.9	98.1	1009.4
24	24.12.2018	6.5	93.6	1020.7
25	25.12.2018	5.0	90.4	1027.9
26	26.12.2018	2.5	94.7	1024.3
27	27.12.2018	3.9	93.5	1018.6
28	28.12.2018	4.0	93.2	1020.9
29	29.12.2018	6.7	97.8	1022.9
30	30.12.2018	9.3	93.3	1014.9
31	31.12.2018	10.4	96.1	1016.0

Table 94: Weather data (daily averages), January 2019

January 2019	date	avg. ambient temperature [°C]	rel. humidity [%]	pressure [hPa]
1	01.01.2019	8.6	96.0	1021.9
2	02.01.2019	5.7	81.8	1026.9
3	03.01.2019	4.7	97.7	1030.6
4	04.01.2019	4.7	96.9	1029.0
5	05.01.2019	7.0	95.0	1022.8
6	06.01.2019	6.7	93.8	1024.9
7	07.01.2019	7.0	92.6	1022.9
8	08.01.2019	7.9	92.6	1007.4
9	09.01.2019	5.5	85.5	1008.4
10	10.01.2019	3.1	92.8	1016.7
11	11.01.2019	5.4	94.2	1015.3
12	12.01.2019	8.0	97.4	1010.0
13	13.01.2019	9.5	99.3	997.2
14	14.01.2019	6.4	95.7	1003.4
15	15.01.2019	7.1	90.1	1010.0
16	16.01.2019	7.6	83.7	1000.9
17	17.01.2019	6.1	92.5	994.7
18	18.01.2019	3.0	92.7	1009.3
19	19.01.2019	1.0	87.7	1006.5
20	20.01.2019	-0.5	87.2	1006.8
21	21.01.2019	-1.5	92.1	1012.9
22	22.01.2019	-1.7	93.6	999.2
23	23.01.2019	0.2	88.7	990.3
24	24.01.2019	-1.0	87.5	1001.5
25	25.01.2019	2.0	91.2	1005.5
26	26.01.2019	8.2	93.0	996.7
27	27.01.2019	7.7	90.5	977.1
28	28.01.2019	4.7	96.0	984.1
29	29.01.2019	4.0	87.3	994.0
30	30.01.2019	1.9	96.2	982.2
31	31.01.2019	0.9	98.5	984.8

Appendix 2 Certificate of Accreditation to EN ISO/IEC 17025:2005

Annex 3 Manual

DAkkS
Deutsche
Akkreditierungsstelle

Deutsche Akkreditierungsstelle GmbH

Beliehene gemäß § 8 Absatz 1 AkkStelleG i.V.m. § 1 Absatz 1 AkkStelleGBV
Unterzeichnerin der Multilateralen Abkommen
von EA, ILAC und IAF zur gegenseitigen Anerkennung

Akkreditierung

Die Deutsche Akkreditierungsstelle GmbH bestätigt hiermit, dass das Prüflaboratorium

TÜV Rheinland Energy GmbH

mit seinen in der Urkundenanlage aufgeführten Messstellen

die Kompetenz nach DIN EN ISO/IEC 17025:2005 besitzt, Prüfungen in folgenden Bereichen durchzuführen:

Bestimmung (Probenahme und Analytik) von anorganischen und organischen gas- oder partikel-förmigen Luftinhaltsstoffen im Rahmen von Emissions- und Immissionsmessungen; Probenahme von luftgetragenen polyhalogenierten Dibenzo-p-Dioxinen und Dibenzofuranen bei Emissionen und Immissionen; Probenahme von faserförmigen Partikeln bei Emissionen und Immissionen; Ermittlung von gas- oder partikelförmigen Luftinhaltsstoffen mit kontinuierlich arbeitenden Messgeräten; Bestimmung von Geruchsstoffen in Luft; Kalibrierungen und Funktionsprüfungen kontinuierlich arbeitender Messgeräte für Luftinhaltsstoffe einschließlich Systemen zur Datenauswertung und Emissionsfernüberwachung; Feuerraummessungen; Eignungsprüfungen von automatisch arbeitenden Emissions- und Immissionsmesseinrichtungen einschließlich Systemen zur Datenauswertung und Emissionsfernüberwachung; Ermittlung der Emissionen und Immissionen von Geräuschen; Ermittlung von Geräuschen und Vibrationen am Arbeitsplatz; akustische und schwingungstechnische Messungen im Eisenbahnwesen; Bestimmung von Schallleistungspegeln von zur Verwendung im Freien vorgesehenen Geräten und Maschinen nach Richtlinie 2000/14/EG und Konformitätsbewertungsverfahren; Schornsteinhöhenberechnung und Immissionsprognose auf der Grundlage der Technischen Anleitung zur Reinhaltung der Luft und der Geruchsimmissions-Richtlinie und der VDI 3783 Blatt 13; Windenergieanlagen: Bestimmung von Windpotential, Energieerträgen, Standorterträgen und Standortgüte nach EEG, standortbezogenen Turbulenzcharakteristika und Extremwinde; Schallimmissionsprognosen, Schattenwurfimmissionsberechnung und Sichtbarkeitsbestimmung; Probenahme und mikrobiologische Untersuchungen von Nutzwasser gemäß §3 Absatz 8 42. BImSchV; physikalische, physikalisch-chemische und mikrobiologische Untersuchungen von Wasser (Abwasser, Wasser aus Rückkühlwerken sowie raumlufttechnischen Anlagen); Probenahme von Abwasser; mikrobiologische und ausgewählte chemische Untersuchungen gemäß Trinkwasserverordnung; Probenahme von Roh- und Trinkwasser; ausgewählte mikrobiologische Untersuchungen von Bedarfsgegenständen und kosmetischen Mitteln; Probenahme anorganischer faserförmiger Partikel sowie von partikel- und gasförmigen luftverunreinigenden Stoffen in der Innenraumluft; ausgewählte mikrobiologische Untersuchungen in Innenräumen; Ermittlung von Aerosolen und Faserstäuben, anorganischen und organischen Gasen und Dämpfen sowie ausgewählten Parametern und/oder in ausgewählten Gebieten bei Arbeitsplatzmessungen gemäß Gefahrstoffverordnung §7, Abs. 10; Modul Immissionsschutz

Die Akkreditierungsurkunde gilt nur in Verbindung mit dem Bescheid vom 02.08.2018 mit der Akkreditierungsnummer D-PL-11120-02-00 und ist gültig bis 10.12.2022. Sie besteht aus diesem Deckblatt, der Rückseite des Deckblatts und der folgenden Anlage mit insgesamt 55 Seiten.

Registrierungsnummer der Urkunde: **D-PL-11120-02-00**

Berlin, 02.08.2018

Valbuena
Im Auftrag Dipl.-Ing. Andrea Valbuena
Abteilungsleiterin

Figure 31: Certificate of accreditation according to EN ISO/IEC 17025:2005

Deutsche Akkreditierungsstelle GmbH

Standort Berlin
Spittelmarkt 10
10117 Berlin

Standort Frankfurt am Main
Europa-Allee 52
60327 Frankfurt am Main

Standort Braunschweig
Bundesallee 100
38116 Braunschweig

Die auszugsweise Veröffentlichung der Akkreditierungsurkunde bedarf der vorherigen schriftlichen Zustimmung der Deutsche Akkreditierungsstelle GmbH (DAkkS). Ausgenommen davon ist die separate Weiterverbreitung des Deckblattes durch die umseitig genannte Konformitätsbewertungsstelle in unveränderter Form.

Es darf nicht der Anschein erweckt werden, dass sich die Akkreditierung auch auf Bereiche erstreckt, die über den durch die DAkkS bestätigten Akkreditierungsbereich hinausgehen.

Die Akkreditierung erfolgte gemäß des Gesetzes über die Akkreditierungsstelle (AkkStelleG) vom 31. Juli 2009 (BGBl. I S. 2625) sowie der Verordnung (EG) Nr. 765/2008 des Europäischen Parlaments und des Rates vom 9. Juli 2008 über die Vorschriften für die Akkreditierung und Marktüberwachung im Zusammenhang mit der Vermarktung von Produkten (Abl. L 218 vom 9. Juli 2008, S. 30).
Die DAkkS ist Unterzeichnerin der Multilateralen Abkommen zur gegenseitigen Anerkennung der European co-operation for Accreditation (EA), des International Accreditation Forum (IAF) und der International Laboratory Accreditation Cooperation (ILAC). Die Unterzeichner dieser Abkommen erkennen ihre Akkreditierungen gegenseitig an.

Der aktuelle Stand der Mitgliedschaft kann folgenden Webseiten entnommen werden:
EA: www.european-accreditation.org
ILAC: www.ilac.org
IAF: www.iaf.nu

Figure 31: Certificate of accreditation according to EN ISO/IEC 17025:2005 - page 2

Annex 2:

Manual

NO_2/NO/NO_x Monitor

2B *Technologies*

OPERATION MANUAL

Model 405 nm

Technical Support:
https://twobtech.com/tech-support.html
techsupport@twobtech.com
+1(303)273-0559

Contents

IDENTIFICATION RECORDS

Record the following information for future reference:

Unit serial number: ____________________________________

Warranty start date: ____________________________________
(date of receipt)

PRINTING HISTORY

This manual covers the Model 405 nm NO_2/NO/NO_x Monitor™ used for measurement of atmospheric nitrogen dioxide (NO_2), nitric oxide (NO) and NO_x (NO + NO_2) over a dynamic range extending from a few parts per billion by volume (referred to herein as simply ppb) up to 10 parts-per-million by volume (ppm) for NO_2 and 2 ppm for NO. The Model 405 nm is approved as a Federal Equivalent Method (FEM) for NO_2 over the range of 0-500 ppb NO_2 for the operating temperature range of 20-30°C. New editions of this manual are complete revisions that reflect updates to the instrument itself, as well as clarifications, additions and other modifications of the text.

Revision A	December 2013
Revision B	February 2014
Revision C	May 2015
Revision D	June 2016
Revision E, serial number 1021-1044	February 2017
Revision F-1, serial number 1045 and above	August 2017
Revision F-2, serial number 1045 and above	November 2017
Revision G-1, serial number 1080 and above	May 2018
Revision G-2, serial number 1080 and above	September 2018
Revision G-3, G-4, serial number 1080 and above	October 2018
Revision G-5, serial number 1080 and above	November 2018

[Among the changes for Revision F-1 is the inclusion of an SD data logger as a standard feature. Revision F-2 included updates to the power and flow specifications, and clarifications to the text regarding the Auto Zero function and interferences. Revision G-1 included the addition of error message codes in the LCD and serial data stream, the removal of the Auto Zero function, updates to the schematic and the Specifications table, reorganization of Sections 1 and 3, and expanded information about zeroing and pressure control. Rev G-2 contains a corrected spare parts list, updated schematic, updated website links, and updated maintenance and troubleshooting information. Rev G-3 updated the internal data logger specs in Section 2 and Maintenance table in Section 6. Rev G-4 updated the Tera Term links and corrected the wire labeling for the Select Switch in Section 12. Rev G-5 added the baud rate choices to the Sections 2, 4.2 and 4.5, which had been available since May 2018.]

TRADEMARKS & PATENTS

2B Technologies™, 2B Tech™, 2B™, NO_2/NO/NO_x Monitor™ and Model 405 nm™ are trademarks of 2B Technologies.

CONFIDENTIALITY

The information contained in this manual may be confidential and proprietary, and is the property of 2B Technologies. Information disclosed herein shall not be used to manufacture, construct, or otherwise reproduce the goods disclosed herein. The information disclosed herein shall not be disclosed to others or made public in any manner without the expressed written consent of 2B Technologies.

WARRANTY STATEMENT AND SAFETY ISSUE

2B Technologies warrants its products against defects in materials and workmanship. 2B Technologies will, at its option, repair or replace products that prove to be defective. The warranty set forth is exclusive and no other warranty, whether written or oral, is expressed or implied. 2B Technologies specifically disclaims the implied warranties of merchantability and fitness for a particular purpose.

Warranty Period

The warranty period is one (1) year from date of receipt by the purchaser, but in no event more than thirteen (13) months from original invoice date from 2B Technologies.

Warranty Service

Warranty Service is provided to customers via web ticket, email and phone support, Monday - Friday, from 9:00 a.m. to 5:00 p.m., Mountain Time USA. The preferred method of contacting us is through our web ticketing software at:

https://twobtech.com/tech-support.html

This way all technical staff at 2B Tech will be alerted of your problem and be able to respond. When you receive an email reply, please click on the Ticket link provided to continue to communicate with us directly over the internet. The web ticket approach to customer service allows us to better track your problem and be certain that you get a timely response. We at 2B Tech pride ourselves on the excellent customer service we provide.

You may also contact us by email at techsupport@twobtech.com or by phone at +1(303)273-0559. In either case, a web ticket will be created, and future communications with you will be through that ticket.

Initial support involves trouble-shooting and determination of parts to be shipped from 2B Technologies to the customer in order to return the product to operation within stated specifications. If such support is not efficient and effective, the product may be returned to 2B Technologies for repair or replacement. Prior to returning the product, a Repair Authorization Number (RA) must be obtained from the 2B Technologies Service Department. We will provide you with a simple Repair Authorization Form to fill out to return with the instrument.

Shipping

2B Technologies will pay freight charges for replacement or repaired products shipped to the customer site. Customers shall pay freight charges for all products returning to 2B Technologies.

Conditions

The foregoing warranty shall not apply to defects resulting from improper or inadequate maintenance, adjustment, calibration or operation by the customer. Maintenance, adjustment, calibration or operation must be performed in accordance with instructions stated in this manual. Use of maintenance materials purchased from suppliers other than 2B Technologies will void this warranty.

Limitation of Remedies and Liability

The remedies provided herein are the customer's sole and exclusive remedies. In no event shall 2B Technologies be liable for direct, indirect, special, incidental or consequential damages (including loss of profits) whether based on contract, tort or any other legal theory. This manual is believed to be accurate at the time of publication and no responsibility is taken for any errors that may be present. In no event shall 2B Technologies be liable for incidental or consequential damages in connection with or arising from the use of this manual and its accompanying related materials. Warranty is valid only for the country designated on the 2B Technologies quote or invoice.

Safety Warning

The Model 405 nm NO_2/NO/NO_x Monitor is designed to use an internal generator of ozone (O_3) to oxidize NO to NO_2. Ozone is a toxic gas and should be handled with caution. Under normal operating conditions, the instrument will produce ~6 ppm O_3 in air. The instrument is equipped with an internal ozone scrubber to remove ozone before venting the sample. Although the scrubber is catalytic, it does have a limited lifetime and should be replaced at least every 12 months. For this reason, it is recommended to properly vent the output of the instrument to protect against any unscrubbed O_3. The outlet should not be vented near the inlet of any NO_x or ozone monitor inlets to avoid false measurements.

The NIOSH exposure limit for ozone is 0.1 ppm or 100 ppb (8-hour time-weighted average).

WARNINGS

ENGLISH

⚠ ***WARNING*:**
Any operation requiring access to the inside of the equipment, could result in injury. To avoid potentially dangerous shock, disconnect from power supply before opening the equipment.

WARNING:
This symbol, ⚠ on the instrument indicates that the user should refer to the manual for operating instructions.

WARNING:
If this instrument is used in a manner not specified by 2B Technologies, USA, the protection provided by the instrument may be impaired.

ESPAÑOL

⚠ ***ATENCION:***
Cualquier operación que requiera acceso al interior del equipo, puede causar una lesión. Para evitar peligros potenciales, desconectarlo de la alimentación a red antes de abrir el equipo.

***ATENCION**:*
Este símbolo, ⚠ en el instrumento indica que el usuario debería referirse al manual para instrucciones de funcionamiento.

ATENCION:
Si este instrumento se usa de una forma no especificada por 2B Technologies, USA, puede desactivarse la protección suministrada por el instrumento.

FRANÇAIS

⚠ ***ATTENTION:***
Chaque opération à l’intérieur de l’appareil, peut causer du préjudice. Afin d’éviter un shock qui pourrait être dangereux, disconnectez l’appareil du réseau avant de l’ouvrir.

ATTENTION:
Le symbol, ⚠ indique que l’utilisateur doit consulter le manuel d’instructions.

ATTENTION:
Si l’instrument n’est pas utilisé suivant les instructions de 2B Technologies, USA, les dispositions de sécurité de l’appareil ne sont plus valables.

DEUTSCH

⚠ ***WARNHINWEIS:***
Vor dem Öffnen des Gerätes Netzstecker ziehen!

WARNHINWEIS:
Dieses, ⚠ auf dem Gerät weist darauf hin, dab der Anwender zuerst das entsprechende Kapitel in der Bedienungsanleitung lesen sollte.

WARNHINWEIS:
Wenn das Gerät nicht wie durch die Firma 2B Technologies, USA, vorgeschrieben und im Handbuch beschrieben betrieben wird, können die im Gerät eingebauten Schutzvorrichtungen beeinträchtigt werden.

ITALIANO

⚠ ***ATTENZIONE:***
Qualsiasi intervento debba essere effettuato sullo strumento può essere potenzialmente pericoloso a causa della corrente elettrica.
Il cavo di alimentazione deve essere staccato dallo strumento prima della sua apertura.

ATTENZIONE:
Il simbolo, ⚠ sullo strumento avverte l’utilizzatore di consultare il Manuale di Istruzioni alla sezione specifica.

ATTENZIONE:
Se questo strumento viene utilizzato in maniera non conforme alle specifiche di 2B Technologies, USA, le protezioni di cui esso è dotato potrebbero essere alterate.

DUTCH

⚠ ***OPGELET:***

Iedere handeling binnenin het toestel kan beschadiging veroorzaken. Om iedere mogelijk gevaarlijke shock te vermijden moet de aansluiting met het net verbroken worden, vóór het openen van het toestel.

OPGELET:
Het symbool, ⚠ geeft aan dat de gebruiker de instructies in de handleiding moet raadplegen.

OPGELET:
Indien het toestel niet gebruikt wordt volgens de richtlijnen van 2B Technologies, USA gelden de veiligheidsvoorzieningen niet meer.

CHINESE

⚠ **警告**：
任何需要接触设备内部的操作均可能造成人身伤害。为避免可能的触电危险，请在打开设备前切断电源。

警告：
这个符号 ⚠ 在仪器上表示用户应参考说明书上的操作指南。

警告：
如果仪器没有按照美国2B科技公司指定方式操作，仪器的保护性能会减弱。

JAPANESE

⚠ **警告**：
機器の内部で操作する時、怪我できます。危険な衝撃を回避するために、機器を開ける前に、電源を切断してください。

警告：
機器でこの記号⚠を見れば、マニュアルを読んでください。

警告：
この機器は2Bテクノロジー会社、
USAの指定でしなければ、機器の保護が損なえます。

1. NO_2/NO/NO_X MONITOR INTRODUCTION

1.1 Overview

The 2B Technologies Model 405 nm NO_2/NO/NO_x Monitor™ is designed to enable accurate measurements of atmospheric nitrogen dioxide (NO_2), nitric oxide (NO) and NO_x (NO + NO_2) over a dynamic range extending from a few parts per billion by volume (referred to herein as simply ppb) up to 10 parts-per-million by volume (ppm) for NO_2 and 2 ppm for NO based on the absorption of visible light at 405 nanometers (nm). The Model 405 nm is approved as a Federal Equivalent Method (FEM) for NO_2 over the range of 0-500 ppb NO_2 for the operating temperature range of 20-30°C (EQNA-0217-243).

The Model 405 nm provides an absolute method for measuring NO_2 based on the Beer-Lambert Law and thus requires only infrequent calibration. The NO_2 measurement is analogous to the measurement of O_3 using a conventional absorbance-based ozone monitor; the two main differences are the use of 405 nm light for NO_2 in place of 254 nm light for O_3, and a much longer path length of ~2 meters (vs. 15-30 cm for ozone) to compensate for the much lower absorption cross section of NO_2. The long path length is achieved by use of a cell with a tubular design that provides low volume and rapid gas exchange.

Nitric oxide is measured by measuring the light intensities with and without ozone added to oxidize NO to NO_2. As described in more detail below, the result is a "semi-direct" measurement of NO in that the NO concentration is output directly and not based on subtraction of NO_2 concentration from a total NO_x concentration. Instead, the NO_x concentration is computed as the sum of the measurements of NO_2 and NO.

The NO_2/NO/NO_x Monitor is provided with a NIST-traceable calibration. Because detection is based on the absolute method of absorbance, frequent calibration of the span (sensitivity) is not required.

1.2 Theory of Operation

Figure 1.1 is a simplified schematic diagram of the Model 405 nm NO_2/NO/NO_x Monitor.

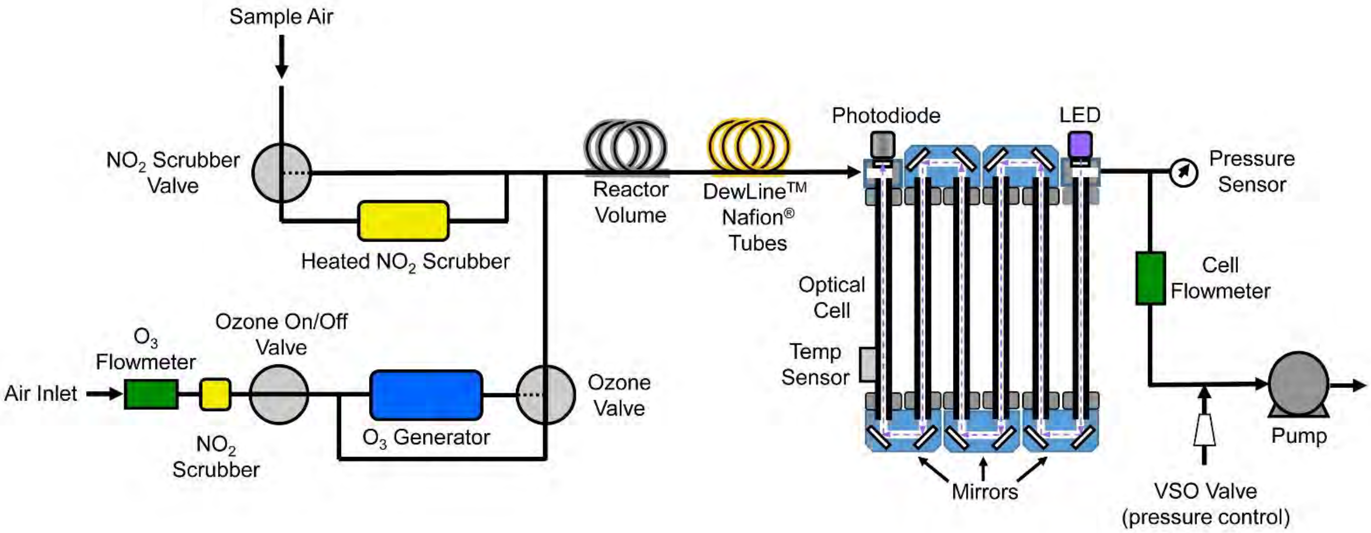


Figure 1.1. ***Schematic Diagram of the Model 405 nm NO_2/NO/NO_x Monitor.***

Sample air is continuously drawn through the instrument by the Pump at a flow rate of ~1.5 L/min. The NO_2 Scrubber Valve alternately bypasses and sends the sample air through a heated NO_2 scrubber to remove all NO_2 in the sample. The NO_2-scrubbed or unscrubbed air passes through the Reactor Volume and the DewLine™ Nafion Tubes (to equilibrate humidity), through the Optical Cell and through the Cell Flow Meter. Alternate switching of the NO_2 Scrubber Valve once every 5 seconds allows the measurement of a light intensity in the absence (I_o) of NO_2 and presence (I) of NO_2. The Beer-Lambert Law is then used to calculate the concentration of NO_2 from I and I_o:

$$[NO_2] = \frac{1}{L\sigma} ln\left(\frac{I_o}{I}\right)$$

Here, L is the path length (~2.1 m) and σ is the absorption cross section (~6.06×10^{-19} cm^2 $molec^{-1}$) for NO_2 averaged over the light-emitting diode (LED) emission centered on 405 nm. The measurement provides an absolute NO_2 concentration in molecules/cm^3. In order to convert this concentration to a mixing ratio (fraction of total air molecules that are NO_2), we also measure the cell temperature and pressure, which determines the total concentration of air molecules. From the temperature and pressure we use the ideal gas law to calculate the concentration of air molecules, M, in the optical cell. Nitrogen dioxide in units of ppb is then given by:

$$[NO_2]_{ppb} = 10^9 \frac{[NO_2]}{[Air]} = 10^9 \frac{RT}{N_A PL\sigma} \; ln\left(\frac{I_o}{I}\right)$$

where N_A is Avogadro's number ($6.02214129 \times 10^{23}$ molec/mol), R is the gas constant ($82.05746\ cm^3\ atm\ K^{-1}\ mol^{-1}$), T is the absolute temperature in K, and P is the cell pressure in atmospheres.

Nitric oxide is measured by bypassing the NO_2 Scrubber and measuring the light intensity while adding (I) or not adding (I_o) ozone to convert NO to NO_2 according to the well-known reaction:

$$NO + O_3 \rightarrow NO_2 + O_2 \qquad (1)$$

As in all our instruments, a DewLine™ Nafion® tube is used to equilibrate humidity during I and I_o measurements, so that any water vapor interference due to refractive effects on light transmission through the optical cell is eliminated. At the conditions of the instrument, reactions of the added ozone with species other than NO are insignificant.

NO_x is obtained by adding the measurements of NO_2 and NO. The instrument may be operated in continuous NO_2 or NO modes, or in a mode where NO_2 and NO are alternately measured, once every 5 seconds.

As discussed above, the pressure and temperature within the absorption cell is measured so that the NO_2 concentration can be expressed as a mixing ratio in parts-per-billion by volume (ppb). The instrument displays and records the cell temperature and pressure in addition to the NO_2 mixing ratio. The cell pressure is displayed and logged in units of either mbar, and the cell temperature in units of °C.

In principle, the measurement of NO_2 by absorbance at 405 nm requires no external calibration; it is an absolute method. However, factors such as variability in the LED peak emission wavelength and band width, and non-linearity of the photodiode and amplifier response, can result in a small measurement error. Therefore, each instrument is calibrated against NIST-traceable standards of NO and NO_2. These results are used to calibrate the Model 405 nm with respect to an offset and slope (gain or sensitivity). The corrections for offset and slope are recorded in the instrument Birth Certificate and on a calibration sticker that can be viewed by removing the top cover of the instrument. These calibration parameters are entered into the microprocessor memory prior to shipment. The user may change the slope and offset calibration parameters from the front panel by entering the Menu if desired. It is recommended that the instrument be recalibrated at least once annually and preferably more frequently. The offset may drift on time scales of hours to days due to temperature change or chemical contamination of the absorption cell. As described below, it is recommended to periodically zero the instrument during use, typically at least daily for most applications.

A voltage sensitive orifice (VSO) valve is used to equalize pressure in the detection cells during I and I_o measurements. This eliminates a potentially large error resulting from the effect of pressure on the transmission of light through the optical bench. We describe this in more detail in a paper published in *Atmospheric Measurement Techniques*, linked here: https://twobtech.com/Model_405_AMT_paper.pdf

2. *SPECIFICATIONS: MODEL 405 nm $NO_2/NO/NO_x$ MONITOR*

Principle of Measurement	Direct absorbance of NO_2 at 405 nm
Federal Equivalent Method (FEM)	Yes, for NO_2 (0-500 ppb, 20-30°C), EQNA-0217-243
Measurement Modes	NO_2 only; NO only; NO, NO_2 and NO_x
Linear Dynamic Range	0-10 ppm for NO_2; 0-2 ppm for NO (FEM approved for 0-500 ppb NO_2 for 20-30°C)
Resolution	0.1 ppb
Precision (1σ rms noise)	< 0.5 ppb or 0.5% of reading (with adaptive filter[1])
Accuracy	Greater of 2 ppb or 2% of reading
Limit of Detection (2σ)	< 1 ppb (with adaptive filter[1])
Flow Rate (nominal)	1.5 Liter/min
Flow Rate Requirement	Minimum: 1.4 Liter/min; Maximum: 1.6 Liter/min
Response Time, 100% of Step Change	10 s for 5-s averaging 20 s with adaptive filter[1]
Measurement Frequency	0.2 Hz (once every 5 s)
Averaging Times	5 s, 1 min, 5 min, 1 hr
SD Card Logger Capacity	Minimum 2 GB (> 5-year capacity for 10-s measurement mode)
Internal Data Logger Capacity	8,192 lines (5-s avg. = 0.47 days; 1-min avg = 5.7 days; 5-min avg = 1.0 mo; 1-hr avg = 0.94 yr)
Concentration Units	ppb, pphm, ppm
Pressure Units	mbar
Temperature Units	°C
T and P Corrected	Yes
Operating Temperature Range	10 to 50°C (FEM approved for 20-30°C for NO_2)
Power Requirement; 5-amp 110/220 VAC Power Pack (provided) or Battery	11-14 V dc or 120/240 V ac, 1.4 A at 12 V, 17 watt Max: 2.9 A at 12 V, 35 watt (warmup)
Size	Rackmount: 17" w × 14.5" d × 5.5" h (43×37×14 cm)
Weight	18.6 lb (8.4 kg)
Data Outputs	RS232, 0-2.5 V Analog Outputs for NO and for NO_2

Data Transfer Baud Rate	2400, 4800, 19200
Output Ranges	User-defined scaling factor in menu
DewLine™	Yes
Long Life Pump	Yes, 15,000 hr
Flow Meter	Yes
Options	Bluetooth for wireless data transmission; USB output (in place of RS232)

[1] An adaptive filter may be selected from the serial menu, making signal averaging similar to competing NO_x monitors. Specifications above are for default parameters: Change Difference = 40 ppb, Change Percent = 10%, Short Filter = 4 pts (20 s), Long Filter = 36 pts (3 min). Adaptive filter parameters may be adjusted by the user. See Section 3.10 and Section 5 of this manual.

3. OPERATION

Please read all the following information before attempting to install the Model 405 nm NO_2/NO/NO_x Monitor. For assistance, please call 2B Technologies at (303)273-0559.

NOTE:

Save the shipping carton and packing materials that came with the Monitor. If the NO_2/NO/NO_x Monitor must be returned to the factory, pack it in the original carton. Any repairs as a result of damage incurred during shipping will be charged.

3.1. Shipping Box Contents

Open the shipping box and verify that it contains all of the items on the shipping list. If anything is missing or obviously damaged, contact 2B Technologies immediately.

3.2. Operation of the Monitor

To operate the NO_2/NO/NO_x Monitor, connect it to an external power source and power the instrument on using the front panel power switch. The instrument requires a 12 V DC source, which can be supplied by the provided 110-220 V AC power adapter or an external battery. The power source should be capable of supplying at least 2.9 amperes of current at 12 V (35 watts). The source can be in the range 11-14 V DC without any detrimental effects on the measurement. Note that the instrument cannot be powered via USB connection to a computer because the minimum power requirements cannot be achieved via this method. (Connection to the computer may only be used for data transmission; see Section 3.7.)

Once turned on, the instrument will display an introductory screen with the version number of the firmware installed on the microprocessor and a display of the time and date. Next, the instrument begins a warmup mode where it will display the target scrubber temperature of 110°C and the current scrubber temperature. After 10-20 minutes from a cold startup, the scrubber will reach the target temperature and the instrument will begin measurements. The instrument briefly will display a status screen showing the state of logging (either the logged number, “OFF,” or “FULL”) and then begin displaying measurements of the species selected for measurement (NO_2; NO; or NO_2 and NO) along with values of the cell flow rate (CF), ozone flow rate (O3F), and the temperature (T) and pressure (P) of the absorption cell. Alternating screens will show the Log state (logged number, OFF, or FULL) and the time and date. The first few readings may be spurious (an error byte message will appear; see Section 9). Valid readings will commence when this message disappears.

3.3. Connections and Setup

1. Attach the sample inlet line to the SAMPLE inlet port (see Section 11, Figure 11.6). The pressure of the sample gas at the inlet port should be at ambient pressure and

constant. The inlet tubing should be made of PTFE (Teflon®), PFA or some other inert material that does not destroy NO_2 or NO and that does not desorb plasticizers and other organics that can contaminate the flow path. The length of tubing should be kept as short as possible to minimize loss of NO_x species to the internal surface and to minimize reaction of NO with ambient ozone. Tygon®, polypropylene (which may look like Teflon®) and metal tubing should not be used. Teflon®-lined Tygon® tubing, which is used inside the instrument, provides the flexibility of Tygon with the inertness of Teflon® and is recommended. A provided Teflon® inlet filter is required to prevent internal contamination of the tubing and optical cell by particulate matter. We recommend a 47 mm PTFE (polytetrafluoroethylene) membrane filter with 5-micron pore size. Also, particles can provide a positive interference to the measurement by absorbing and scattering light from the LED source. The filter should be tested for NO_2 and NO loss by measuring ambient NO_2 and NO with and without the filter attached. Replacement filters are available through 2B Technologies. See our website: https://twobtech.com/parts-online.html.

2. Vent the EXHAUST port to atmospheric pressure and out of the room or shelter. The monitor has a internal scrubbers that remove ozone (produced to oxidize NO to NO_2) and NO_2 from the sample before exiting the instrument though the EXHAUST port. However, it is recommended that the pump exhaust be vented to a well-ventilated area outside the room or shelter in case either scrubber fails.

3.4. Pre-Operation Flow Settings of the Monitor

The Model 405 nm has two independent flows, which need to be verified (via the instrument's LCD menu or serial menu) and adjusted before operating the instrument. The two volumetric flow rates that are independently adjusted are:

Cell Flow Rate (1400-1600 cm^3/min): The cell flow rate of sample gas and ozone/air through the reactor volume and optical cell.

Ozone Flow Rate (60-80 cm^3/min): The flow rate of ozone/air mixed into the sample flow stream.

These flow rates are adjusted to be in the ranges specified above at the factory. However, due to changes in altitude and thus pressure, the two flow rates need to be verified and adjusted by the user to be within the specified ranges if necessary. To do this, follow the flow rates on the LCD screen (Section 4.3.1) or serial output (see Section 3.7). The Cell Flow, displayed as **CF**, should be in the range 1400-1600 cm^3/min. This flow can be adjusted by the needle valve located on the back panel labeled "Cell Flow." The Ozone Flow, displayed as **O3F**, should be in the range 60-80 cm^3/min. The Ozone Flow can be adjusted by the needle valve located on the back panel labeled "O3 Flow." Once these flows have been verified and adjusted they should not need to be re-adjusted unless the instrument's location changes in altitude.

After adjusting the flow, the instrument power should be cycled on and off before proceeding.

3.5. Data Averaging and Data Logging

When first turned on, the instrument will start making measurements at a rate of once every 5 s (unless a different averaging time was previously chosen; see Section 4.4). Internally generated data may be logged in the internal data logger. Up to 8,192 data lines containing log number, NO_2, NO, NO_x, NO_{2_zero}, $NO_{\_zero}$, Cell Temperature, Cell Pressure, Cell Volumetric Flow Rate, Ozone Volumetric Flow Rate, Sample Photodiode Voltage, O_3 Generator Photodiode Voltage, Heated Scrubber Temperature, Date, Time, and Status may be stored in internal memory. Averaging times of 5 s, 1 min, 5 min and 1 hr may be selected from the menu (Section 4.4), thereby allowing the instrument to operate for 1.4 days, 5.7 days, 1.0 months and 0.94 years, respectively, before filling the memory.

3.6. Collecting Data from the Analog Outputs

The data may be logged in real time using a data logger attached to the BNC analog outputs. There are two analog outputs: one for NO_2, and one for NO. The range of each analog output is 0-2.5 V, and the same user-selected scaling factor is applied to both outputs. The output is scaled according to a sensitivity you define in the menu. For example, you may define 2.5V = 250 ppb. In that case, the maximum output is 250 ppb, and 10 mV is equal to 1 ppb. There is a small positive offset, typically 2 mV in the analog output, but this offset varies from instrument to instrument. The offset can be measured by simultaneously observing the panel display and measuring the analog output with a voltmeter.

3.7. Collecting Data over the Serial Port in Real Time

To transmit data to a computer over the serial port in real time, connect the instrument to the computer using the 9-pin cable provided (and a serial-to-USB adapter cable if necessary). Note that the 9-pin cable provided is a “straight-through” female-female serial cable. A “cross-over” cable will not work. Start your data acquisition software, preferably using the 2B Technologies Display and Graphing Software (free download from https://twobtech.com/docs/docs_software.htm; see Appendix A for information on working with this software). Other terminal emulation software such as HyperTerminal (a program provided with earlier versions of Windows) or Tera Term may be used as well. Be sure to specify the baud rate setting of your data acquisition software to match the baud rate setting of your instrument. Note that the baud rate of the instrument is 2400.

The NO_2, NO and NO_x mixing ratios (ppb, pphm, ppm), internal cell temperature (°C), cell pressure (mbar), volumetric flow rate (cc/min), date, and time are sent as comma-delimited ASCII text to the serial port (2400 baud; 8 bits; no parity; 1 stop bit) every 5 seconds, 1 minute, 5 minutes, or 1 hour, depending on the averaging time selected from the microprocessor menu. Time is provided in 24-hour (military) format, and the date is given in European style (day/month/year). The user should separately make note of the instrument settings for units (NO_2/NO/NO_x) and averaging time.

A typical data line might read:

```
67.4,44.2,111.6,30.3,980.6,1576,76.2,1.2743,1.0151,110.2,00,12/07/17,18:31:27,80
```

where:

NO_2 = 67.4 ppb
NO = 44.2 ppb
NO_x = 111.6 ppb
Cell temperature = 30.3°C
Cell pressure = 980.6 mbar
Cell volumetric flow rate = 1576 cc/min
O_3 volumetric flow rate = 76.2 cc/min
Sample photodiode voltage = 1.2743 volts
O_3 generator photodiode voltage = 1.0151 volts
Heated scrubber temperature = 110.2°C
Error Byte = 00 *(No error; see Section 9 for error codes)*
Date = July 12, 2017
Time = 6:31:27 pm
Status = 80 *(Measuring NO_2 and NO) (see Section 5 for status codes)*

If the NO_x Monitor has been set to the log data mode, the output serial data line will be preceded by the log number; e.g.,

```
289,67.4,44.2,111.6,30.3,980.6,1576,76.2,1.2743,1.0151,110.2,00,12/07/17,18:31:27,80
```

where 289 is the log number.

In addition to data lines, messages are written to the serial port when logging is begun or ended, when transmission of data from the logger is begun and ended, when data collection is interrupted (e.g., due to a power failure) and when the averaging time is changed. Section 5 of this manual describes the serial menu and how to access it.

3.8. Logging Data Using the SD Card

2B Technologies provides a SD card logger with the Model 405 nm NO_2/NO/NO_x Monitor, along with an SD card and an SD card reader. When inserted into the instrument (bottom right of the Monitor's front panel), the SD card automatically begins to collect and store data. (The internal data logger described in Section 3.5 will also be logging data <u>if</u> logging has been selected from the **Dat** submenu.) The data are saved to a .txt file in the following format:

```
67.4,44.2,111.6,30.3,980.6,1576,76.2,1.2743,1.0151,110.2,00,12/07/17,18:31:27,80
```

where:

NO_2 = 67.4 ppb
NO = 44.2 ppb
NO_x = 111.6 ppb
Cell temperature = 30.3°C
Cell pressure = 980.6 mbar
Cell volumetric flow rate = 1576 cc/min
O_3 volumetric flow rate = 76.2 cc/min
Sample photodiode voltage = 1.2743 volts

O_3 generator photodiode voltage = 1.0151 volts
Heated scrubber temperature = 110.2°C
Error Byte = 00 *(No error) (see Section 9 for error codes)*
Date = July 12, 2017
Time = 6:31:27 pm
Status = 80 *(Measuring NO_2 and NO) (see Section 5 for status codes)*

If the NO_x Monitor has been set to the log data mode, the output serial data line will be preceded by the log number; e.g.,

```
289,67.4,44.2,111.6,30.3,980.6,1576,76.2,1.2743,1.0151,110.2,00,12/07/17,18:31:27,80
```

where 289 is the log number.

Data files on the SD card are named "LOG01.txt," "LOG02.txt," etc. Note that the SD card contains a LOGCON.txt file that should not be modified or deleted.

Data logging on the SD card will continue until the instrument is powered off. A new data file is begun each time the instrument is powered on. *(Note warning below.)*

To eject the SD card, push it in to activate the spring mechanism. Insert the SD card into an SD card reader (one is supplied by 2B Technologies with the instrument) to download the data to your computer. *(Note warning below.)*

Important: When removing the SD card or powering off the instrument, up to 5 lines of data could be lost. (Note that if internal data logging was enabled, any lost lines could be retrieved from the internal data file.)

The Model 405 nm NO_2/NO/NO_x Monitor is compatible with SD and SDHC memory cards. We recommend using the SD cards available on the 2B Technologies website (https://twobtech.com/parts-online.html). Prior to first use, SD cards must be formatted to FAT32. As mentioned above, an SD card and SD card reader are supplied with the Model 405 nm Monitor. See Technical Note 036 for more information about logging and reading data via the SD card.

3.9. Measurement of the Zero Offset

The electronic zeros for NO_2 and NO may be periodically measured by either providing NOx-free air (typically zero grade air) or attaching a NO_x scrubber to the air inlet for a period of 5-10 minutes. Section 8 gives procedural recommendations for proper measurement of the instrumental zero offset. The observed offset, which can amount to a few ppb, can be adjusted by either changing the zero calibration parameter from the front panel, as described in Section 4.5.2 below, or by correcting the data at a later time. When making continuous measurements, it is recommended to check the zero offset at least once daily. Please refer to Section 8 for more detail.

3.10. Adaptive Filter

The Model 405 nm firmware processes sample concentration data through a built-in adaptive filter. During operation, the firmware may automatically switch between two different filter lengths based on the conditions at hand. During the measurement of stable concentrations, the firmware, by default, computes an average of the last 36 raw measurements, or 3 minutes of measurements. This provides smooth and stable readings by averaging out a considerable amount of random noise to improve the precision. If the filter detects rapid changes in concentration, the filter reduces the averaging to only 4 samples or 20 seconds to allow the analyzer to respond more quickly. Two conditions must be simultaneously met to switch to the short filter. First, the instantaneous concentration must differ from the average in the long filter by at least 40 ppb. Second, the instantaneous concentration must differ from the average in the long filter by at least 10% of the average in the long filter. The lengths of the long and short filter can be changed as well as the minimum difference and percent difference. This can be done via the serial connection as outlined in the Serial Menu section in this manual (Section 5). To disable the adaptive filter, set the short filter length to 1, the difference to 0, and the percent to 0.

3.11. Summary of Operating Recommendations

The following table summarizes operating recommendations mentioned in this manual.

Operating Recommendation	Frequency	Section Reference
Measure and adjust cell flow rate and ozone flow rate before operating instrument (restart instrument after adjustment of flows)	Whenever the instrument's location changes in altitude	3.4
Allow ~20 minutes for instrument warmup	Each startup	3.2
Inlet tubing should be made of inert materials, such as PTFE, PFA, FED, PVDF (do not use Tygon®, polypropylene, or metal tubing)	Each use	3.3
Use a Teflon or PVDF inlet filter; test it for NO_2 and NO loss	Each use	3.3
Vent exhaust to atmospheric pressure and out of room or shelter	Each use	3.3; also page vii
Check the span and zero offset	Periodically. For most applications, the zero offset should be checked daily.	8
Perform multipoint calibration	• Annually • Any time major disassembly of components is performed • Any time the zero or span checks give results outside of the acceptable limits	4.5.2; 7
If strong temperature fluctuations are expected, place the instrument in a thermally insulated box	User-defined	2
Use adaptive filter to improve precision if rapidly changing NO/NO_2 concentrations are occurring or are anticipated	User-defined	3.10; 5

4. THE MENU

4.1. Accessing the Main Menu

The instrument menu is accessed using the Select switch on the front panel of the instrument:

To reach the menu, hold in the Select switch (for up to several seconds) until the display shows: **Menu**. Then release the switch. The panel will now display:

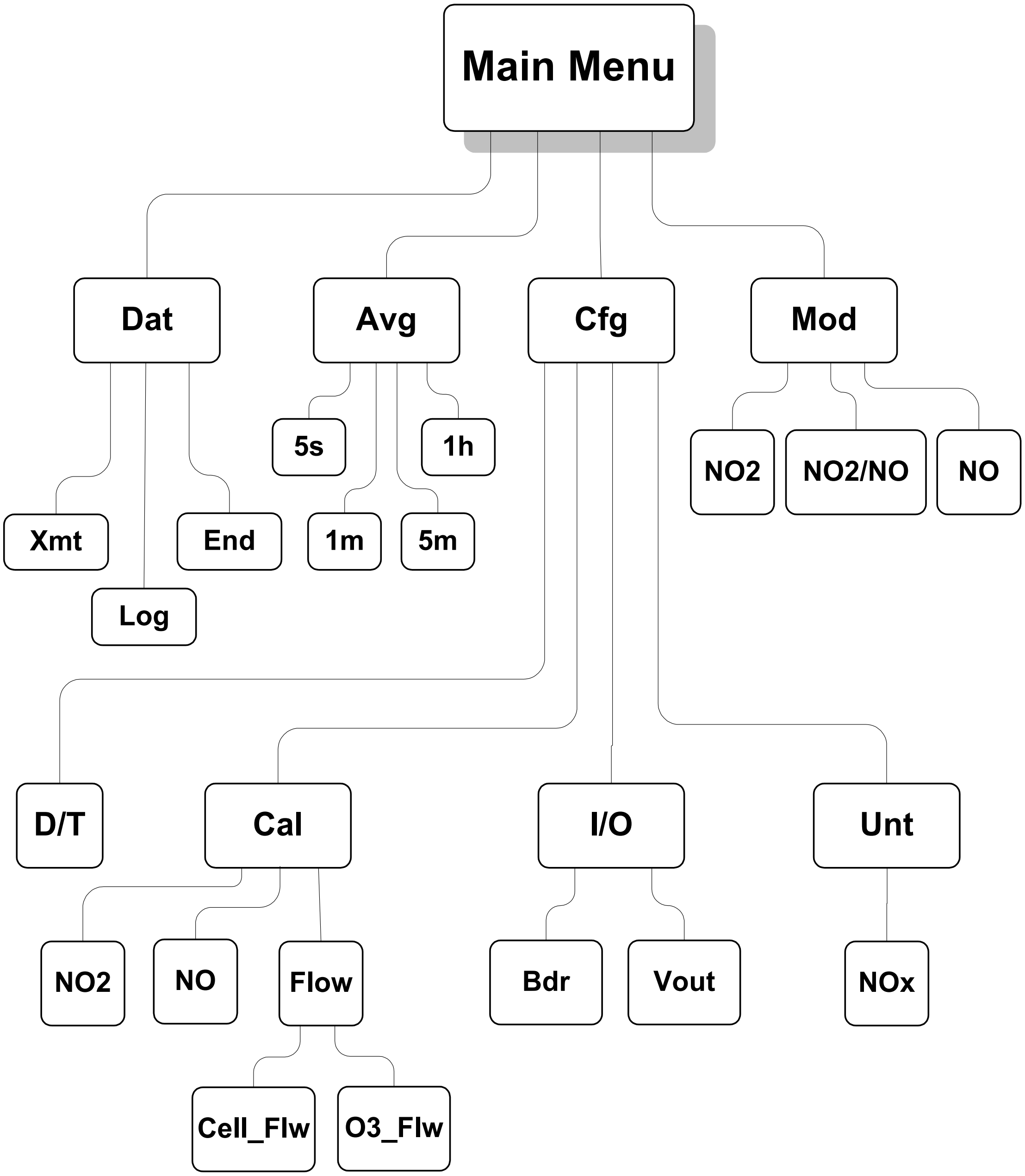
Menu
Dat Avg Cfg Mod ←

where **Dat**, **Avg**, **Cfg**, and **Mod** are submenus that may be selected. A blinking cursor will show across the **D** of the **Dat** submenu. The Select switch may be rotated clockwise or counterclockwise to move the cursor under the first letter of one of the other submenus. To select a particular submenu, move the cursor under the first letter of the submenu and click (press in) the Select switch. To exit the Main Menu and begin making measurements again, select and click on the left arrow (←). Note that "←" always takes you up one level in the menu.

A diagram of the menu structure and detailed explanations of each of the submenus are given below.

4.2. Menu Tree

The following diagram summarizes the complete menu.



4.3. Dat Submenu: Internal Data Logging

4.3.1. To Start Logging Data

Select the **Dat** submenu from the Main Menu using the Select switch. The display will now show:

Data Menu
Xmt Log End ←

To start logging data, rotate the Select switch to move the cursor to **Log** and click to select the logging mode. You will then be asked whether you want to overwrite the data stored in the logger:

This will overwrite
all existing data.
Are you sure?
No Yes ←

If you select yes and start logging, all data previously stored in the logger will be irretrievably lost. If you have data in the logger that you want to keep, be sure to download it before restarting logging.

If you are ready to start logging, then select **Yes** by moving the cursor under **Yes** and clicking. Either selection will return you to the **Dat Menu**. To start data acquisition, select ← and click to return to the main **Menu** and the select ← to begin making measurements.

When measurements resume, the display might read:

```
          NO2= 34.8 ppb
---------------------------------------------
 LOG=193:0          Tsc=112
 14:49              04/07/2017
```

where the **NO2** (or **NO**) is the most current measurement of that species, **LOG** is the current log number (193 in this case), **Tsc** is the temperature (Celsius) of the NO_2 scrubber, the time of the measurement is 14:49 (2:49 pm on 24-hr clock) and the date is 4 July 2017 (European style). The "0" in "193:0" refers to the number of 5-second data points that have been measured so far for inclusion in the next average to be displayed and logged (in this case, "0" is displayed because no averaging has been selected). After 5 seconds, as an example, the display will be replaced by:

```
   NO2= 33.7 ppb
-----------------------------
 CF=1525   O3F=75
 T=35.2    P=985.7
```

where **NO2** (or **NO**) is the value most recently written to the logger, **CF** is the cell flow rate, **O3F** is the ozone flow rate (if **NO** is being measured), **T** is the temperature in Celsius, and **P** is the cell pressure in millibar.

If averaging has been selected (see Section 4.4 below), then the first display above will be replaced by:

AvgNO2= 56.7 ppb

LOG= 193:4 Tsc=111
14:49 04/07/2017

Again 193 refers to the most recent log number. The “4” in 193:4 refers to the number of 5-s data points that have been measured so far for inclusion in the next average to be displayed and logged. If 5-s averaging is used, this number will always be 0. If 1-min averaging is used, this number will increment from 0 to 11; for 5-min averaging, the number will increment from 0 to 59; and for 1-hr averaging, it will increment from 0 to 719. This number is displayed so that the user will know how many more 5-s measurements need to be made before a new average is displayed and logged.

Note that entering the menu will interrupt the averaging interval that is in progress, and the averaging interval will start over when the menu is exited and measuring is resumed.

If an “E:” followed by a 2-character code appears at the center of the bottom line of the LCD readout, an error has occurred, and one or more instrument parameters are out of range (e.g., scrubber temperature, cell flow rate, cell voltage, etc.). See Section 9 for a detailed list of error codes and their meaning.

If there is a power failure while the instrument is in the logging mode, logging will resume after power is restored. A note of

Data Interrupt

will be written to the logger prior to writing the first new data line. In the case of a power failure, a data line may be lost because the microprocessor writes to the logger memory in groups of two lines. All data residing only in the volatile memory of the microprocessor are lost when power is interrupted.

The instrument can accommodate multiple data interruptions due to power failures. For example, one can purposely switch the instrument off, move to another location and restart logging simply by turning the instrument back on.

4.3.2. To Stop Logging Data

Hold the Select switch down to obtain the **Menu**. Go to the **Dat** submenu by clicking on **Dat**. Choose and click on the **End** function. This will end data logging. You may now transmit the data to a computer by clicking on **Xmt** (see below). Alternatively, you may return to the **Menu** and resume measurements by clicking on ←. The stored data will reside in memory (even when new measurements are being made) and can be transmitted using the **Xmt** function as often as you like. However, all stored data are lost once logging is started again using the **Log** function. Thus, you should always transmit your data to a computer before restarting logging.

If you fail to **End** logging prior to transmitting the data using the **Xmt** function, the instrument will automatically execute the **End** function for you prior to transmitting the data.

4.3.3. To Transmit Logged Data

Connect the serial port of the instrument to the serial port of your computer using the cable provided. If your computer does not have a serial port, you can use the computer's USB port by means of a serial-to-USB adapter. Such adapters are available in most computer stores or can be supplied by 2B Tech. Enable a data acquisition program on the computer such as the 2B Technologies Display and Graphing Software (free download available from the 2B Technologies website at https://twobtech.com/docs/docs_software.htm), Microsoft HyperTerminal (available on earlier Windows® platforms, usually in Start/AllPrograms/Accessories/ Communications/HyperTerminal) or Tera Term, which can be downloaded at:

https://twobtech.com/teraterm-4.100.exe

Note that a disadvantage of HyperTerminal is that it has a 500-line buffer limit. However, all programs may be used to log an unlimited number of data lines to a file on your computer. For more details, see our Tech Note #007 here:

https://twobtech.com/docs/tech_notes/TN007.pdf

Hold down the Select switch to obtain the **Main Menu**. Go to the **Dat** submenu by clicking on **Dat**. Next, click on **Xmt**. The message “Logged Data” will be written to the serial port, followed by a carriage return and all of the lines of logged data. After all data are transmitted, the message “End Logged Data” and a carriage return are written. After transmission is complete, you can return to any position in the menu or resume NO_2 measurements. The logged data continues to be available for transmission until a new data log is started.

4.4. Avg Submenu: To Average Data

Hold down the Select switch to obtain the **Menu**. Select and click on **Avg** to obtain the **Avg** menu:

Avg Menu
5s 1m 5m 1h ←

Use single clicks to move the cursor to **5s**, **1m**, **5m** or **1h** for averaging times of 5s, 1 min, 5 min or 1 hr averaging, respectively. Then click on the averaging time you want to use. To return to the Main Menu, click on **←**. To exit the Main Menu and start acquiring data, click on ← again.

While in averaging mode, the current 5-s measurement is displayed alternately with the average value, as discussed in Section 4.3 above. Note that entering the menu will interrupt the averaging interval that is in progress, and the averaging interval will start over when the menu is exited and measuring is resumed.

Averaged data may be logged, thereby greatly extending the length of time that the data logger can be used.

4.5. Cfg Submenu: Instrument Configuration

Several different parameters including date/time, calibration, and input/outputs can be accessed and set through the configuration or **Cfg** submenu.

4.5.1. To Set the Time and Date

From the **Main Menu**, select the **Cfg** submenu. Next, select the **D/T** submenu. The display will read, for example:

Set Date and Time

14:32:21 ←
17/07/2017

meaning that it is 21 seconds after 2:32 p.m. on July 17, 2017 (military time and European date). To change a number in the date and time, rotate the Select switch to underline the numeral you want to change. A single click then causes a blinking cursor to cover that numeral. The number can then be changed by rotating the Select switch. Once the number is correct, click on the Select switch to turn off the blinking cursor. You may now rotate the Select switch to choose another numeral to change. Once the time and date is correct, clicking on ← will set the internal clock to that time and return the display to the **Cfg** menu. As in setting a digital watch, the seconds should be set in advance of the real time since the clock starts to run again only when the set time is entered; in this case by clicking on ←.

4.5.2. Calibration Parameters - Overview

All calibration parameters can be accessed through the **Cfg / Cal** submenu. Slope and offset calibration parameters may be set for NO_2, NO, Cell Flow Rate, Ozone Flow Rate, and internal Ozone Source. Calibrations are performed at 2B Technologies and these calibration parameters are set prior to the instrument being packaged and shipped. Flow rates and flow meter calibration parameters should not be changed unless certain parts of the instrument are replaced which are normally done by technicians at the factory. The user should check and adjust flow rates if the instrument is moved to a different altitude (see Section 3.4). You may want to change the NO_2 and NO calibration parameters based on your own calibrations.

4.5.3. To Set the NO_2 and NO Calibration Parameters

The instrument is calibrated at the factory, where slope and offset parameters for NO_2 and NO are entered into the instrument's memory. These preset calibration parameters are given in the instrument's Birth Certificate and recorded on the calibration sticker viewable with the top cover removed. However, the calibration parameters may be changed by the user. For example, it may be desirable to provide a positive offset by a known amount (e.g., 10 ppb) if the analog output is being used for external data logging since the analog output does not go negative below zero ppb. Because of noise and/or an inherent offset, some measured values will be below zero at very low NO_2 or NO mixing ratios. (When measuring zero NO_2 or NO concentration, there should be an equal number of negative and positive values if the instrument is zeroed.) Also, the instrument zero may drift by a few ppb over time. For this reason, frequent zeroing of the instrument is recommended. For most applications, zeroing the instrument once or twice daily, for a duration of at least 5 minutes, is sufficient. Any change in the slope (gain) of the instrument is likely due to a serious problem such as contamination, an air leak, obstruction of air flow, or a contaminated NO_2 or NO_x scrubber, but it also can be adjusted. Once the zero of the instrument is corrected, the slope may be adjusted so that the instrument readout agrees with a standard NO_2 or NO source or with the readout from another instrument whose calibration is considered to be accurate.

To adjust the calibration slope and zero offset calibration parameters, first access the **Cal** menu from the **Cfg** menu. There are three submenus:

Cal Menu
NO2 NO Flow ←

To change the NO_2 or NO calibration parameters, select **NO2** or **NO** from the **Cal** menu. Now you can select either **Slope** or **Zero** to adjust slope factor or the zero offset. For example, for NO_2, the submenu will appear as:

NO2 Cal Menu
Slope Zero ←

Selecting **Slope** will allow you to set the slope (sensitivity) value one digit at a time out to three decimal places.

NO2 Slope Cal
Slope = 1.011 ←

To change a digit in the slope or the offset, rotate the Select switch to underline the numeral you want to change. A single click then causes a blinking cursor to cover that numeral. The number can then be changed by rotating the Select switch. Once the number is correct, click on the Select switch to turn off the blinking cursor. You may now rotate the Select switch to choose another numeral to change. Once the slope is correct, clicking on ← will set the slope to that value and return the display to the **NO2 Cal Menu** menu.

Selecting **Zero** from the menu will display:

NO2 Zero Cal
Zero = -002.5 ←

Here Zero is the offset applied (in this case -2.5 ppb). The Zero value can be edited in the same manner as the Slope value. <u>For both NO and NO2, the Zero value must be entered in units of ppb.</u> If the calibration was performed in other units, convert the offset to ppb and enter that value.

The value of Zero is added to the measured NO_2 or NO value, and the value of Slope is then multiplied by the measured value. For example, if the instrument reads an average of 3.2 ppb with an external scrubber in place, the value of Z should be set to –003.2. If after correction for the zero, the instrument consistently reads 2.3% low, the value of Slope should be set to 1.023.

4.5.4. To Set the Flow Meter Slopes

Two different flow measurements are critical to the performance of the instrument: one is the cell flow rate and the other is the ozone flow rate. Do NOT change these settings unless you contact 2B Technologies. To change the flow meter slope (sensitivity) calibration parameters, access the **Cfg / Cal / Flow** submenu:

Flow Cal Menu
Cell_Flw O3_Flw ←

Selecting the Cell_Flw submenu allows you to change the slope calibration parameter for the cell flow rate:

CFlow Cal Menu
CF = 1.03 ←

You may change this multiplicative calibration parameter by selecting the first numeral, and then rotating the select switch to scroll up to the desired decimal value, and deselecting. To change the ozone flow meter calibration parameters, select **O3_Flw** and set in the same manner as for the cell flow rate.

4.5.5. To Change the Analog Output Scaling Factor

Analog outputs proportional to NO_2 and NO concentrations are provided via BNC connectors at the back of the instrument for those who want to record NO_2 and NO concentration data with a chart recorder or external logger. The full scale of each analog output is 2.5 V, and the same scaling factor is applied to both analog outputs. From the **Cfg** submenu, select **I/O** to give the input/output menu, for example:

I/O Menu
Bdr Vout ←

In the **Cfg / I/O** submenu, electing **Vout** displays the submenu:

Analog Output
1V = 00200 ppb ←

In this example, the output scaling factor is set as 1.0 Volt = 200 ppb. Since the maximum output voltage is 2.5 V, the maximum output concentration in this case is 500 ppb, and 1 ppb will provide an output of 5 mV. You can use the Select switch to change the scaling factor to the value of your choice by selecting and changing the individual digits in the scaling factor. A click on ← returns the display to the **I/O** menu.

4.5.6 To Change the Output Baud Rate

From the **Cfg** submenu, select **I/O** to give the input/output menu, for example:

I/O Menu

Bdr Vout ←

Selecting **Bdr** and clicking allows you to change the baud rate used for data transmission. The choices are 2400, 4800, and 19200 bps. The submenu appears as:

2400 4800 19200 ←

After clicking on a chosen baud rate, use ← to return to the **I/O** menu.

4.5.7. Measurement Units for NO_2 and NO

Select the **Cfg / Unt** menu to display the following:

NOx Units
NOx: ppb ←

Select the units (ppb in this case) and rotate the Select switch to cycle the cursor between the choices of units. NO_2 (and NO) units may be selected as ppb, pphm and ppm. A click on ← returns the display to the **Unt** menu.

4.6. Mod Submenu: Measurement Modes

The Model 405 nm has the capability to measure nitrogen dioxide and nitric oxide each individually or simultaneously (5 seconds apart). There are 3 measurement modes available: NO_2 mode, NO mode, and NO_2 and NO mode. The measurement mode can be changed by entering the **MOD** menu and selecting either “NO2”, “NO2/NO”, or “NO”. If using a serial connection, the mode can be changed using serial commands “G” for NO_2 mode, “B” for NO_2 and NO mode, or “N” for NO mode. The status byte at the end of the serial stream tells which mode you are currently in (see Section 5 for status codes).

4.6.1. NO_2 Mode

This measurement mode uses two 5 second cycles to measure I and I_o for NO_2. After each cycle, a new measurement of nitrogen dioxide is computed and output to the LCD and through the serial port depending on what averaging frequency is selected (5 sec, 1 min, 5 min, or 1 hr).

4.6.2. NO_2 and NO Mode

This measurement mode uses three 5-second cycles to measure I_o for NO_2, I for NO_2, which is also I_o for NO, and I for NO. After each 5-second cycle, a new measurement of nitrogen dioxide and nitric oxide is computed and output to the LCD and through the serial port, depending on what averaging time is selected (5 sec, 1 min, 5 min, or 1 hr).

4.6.3. NO Mode

This measurement mode uses two 5 second cycles to measure I and I_o for NO. After each cycle, a new measurement of nitric oxide is computed and output to the LCD and through the serial port, depending on what averaging frequency is selected (5 sec, 1 min, 5 min, or 1 hr).

5. REMOTE CONTROL VIA SERIAL CONNECTION

Measurements and logging tasks can be accessed via the serial port using the 2B Technologies Display and Graphing software (available as a free download from https://twobtech.com/docs/docs_software.htm; see Appendix A for information on working with this software) or a terminal emulator such as Tera Term or HyperTerminal running on an attached computer. Commands can be sent using the terminal emulator set with the properties listed in the section of this manual entitled "Collecting Data over the Serial Port in Real Time" (Section 3.7). Listed below are the lower-case letters that are commands for performing certain operations while the instrument continues to measure:

Key Stroke	Function
l	Start logging.
t	End logging and transmit data.
e	End logging.
N	Set the current mode to measure Nitric Oxide.
G	Set the current mode to measure Nitrogen Dioxide.
B	Set the current mode to measure both NO_2 and NO.
h	Output the serial header.

5.1. Serial Menu

If the letter **m** is sent as a command, measurements will stop and **menu>** will be displayed in the terminal emulator window. When the serial menu is accessed, the instrument is no longer making measurements; it is waiting for the next command to be entered. The following is the list of menu items accessible from this point:

Key Stroke	Function
l	Start logging.
t	End logging and transmit data.
e	End logging.
a	Set average and output frequency.
z	Set the NO_2 zero offset calibration factor (in units of ppb).
s	Set the NO_2 slope calibration factor.
o	Set the NO zero offset calibration factor (in units of ppb).
g	Set the NO slope calibration factor.
c	Set the time and date. **n** Leave time and date unchanged. **t** Change time (must enter new values). **d** Change date (must enter new values).
d	Turn the LCD backlight on.
f	Turn the LCD backlight off.
i	Adaptive filter - Change Difference (ppb).
q	Adaptive filter - Percent (%).

k	Adaptive filter - Long Average (number of points).
m	Adaptive filter - Short Average (number of points).
h	Output the serial header.
?	Output this help menu.
x	Exit the serial menu.

5.2. Status Codes

The current measurement mode can be determined from the status byte in each serial data line. The following describes all combinations of the status byte and the corresponding measurement mode:

80 = Measuring NO_2 and NO
10 = Measuring NO_2
20 = Measuring NO

6. MAINTENANCE

The Model 405 nm NO_2/NO/NO_x Monitor is designed to be nearly maintenance free. Components that require routine maintenance include the ozone and NO_2 scrubbers on the cell exhaust and the DewLine^{TM} Nafion tubing on the cell inlet, all of which should be changed every year, and the air pump. The pump has a rated lifetime of 15,000 hours (~1 year and 8 months) of operation and will need to be replaced when the flow rates can no longer be brought into range (see Section 3.4). Operation with a high restriction on the sample inlet will reduce the lifetime of the pump. The instrument is designed so that pump replacement is relatively easy. Other user-serviceable components include the LED, clock battery and solenoid valves, which are easily replaced should they fail. In addition, the inlet filter (user supplied) should be changed as recommended by the filter manufacturer. See Section 9 for a description of Error Codes and see Section 10 of this manual for troubleshooting information.

A wide range of Technical Notes are provided on the 2B Tech website. The complete list with links may be found at https://twobtech.com/docs/docs_tech_notes.htm
These Tech Notes are continuously updated and new ones created.

Also, please note that all 2B Tech instrument manuals are posted online at:

https://twobtech.com/downloads.html

For your convenience, a Service Log, which may be printed, is provided at the end of this manual for recording calibrations, replacement of pumps, LEDs, etc. Records of repairs made at 2B Tech are maintained in a database at 2B Technologies as well. That database also includes detailed information about the construction and initial calibration of your instrument, including digital of photos of its interior.

Maintenance Recommendation	**Frequency**	**Section Reference**
Recalibrate instrument	At least once per year or at 4000 hours; sooner if span and offset are large, or if instrument undergoes major disassembly	7
Check flow path for contamination	Occasionally	Contact 2B Tech if contamination is suspected
Check heated NO_2 scrubber, exhaust gas NO_2 and O_3 scrubbers, and DewLine^{TM} Nafion tubing and replace if needed	Every 6 months of continuous operation (~4,000 hrs); otherwise annually	6 [contact 2B Tech for instructions if heated NO_2 scrubber needs replacement]
Monitor flow rates and replace pump if indicated	Nominal 15,000 hours pump lifetime	6

7. CALIBRATION

Calibration of the Model 405 nm NO_2/NO/NO_x Monitor is recommended at least annually, either by the user (recommended procedure described below) or by returning the instrument to 2B Technologies for calibration servicing.

7.1. Introduction

Every analytical instrument is subject to some drift and variation in response, making it necessary to periodically check the calibration. Dynamic calibration is a multipoint check where gas samples of known concentration are sampled by the instrument in order to determine a calibration relationship. For more information on calibration of NO_2 and NO monitors, please refer to the related information in Code of Federal Regulations (Title 40, Part 50, Appendix F: https://www.gpo.gov/fdsys/pkg/CFR-2011-title40-vol2/pdf/CFR-2011-title40-vol2-chapI.pdf).

Calibration is the process of adjusting the gain and offset of the Model 405 nm against some recognized standard. The reliability of the data collected from any analytical instrument depends on the accuracy of the calibration, which is largely dependent upon its analytical traceability to a reference material or reference instrument calibration.

The calibration of NO_2 and NO monitors using compressed gas mixtures is unreliable because the gases are lost by reaction and adsorption in the cylinder and on gas handling equipment. When concentration standards are required, NO_2 and NO concentrations are generated by diluting a high concentration NO mixture and converting a fraction of the NO to NO_2 via the gas-phase titration reaction with ozone. The depletion of NO measured by the Model 405 nm provides the calibration for NO, and the appearance of NO_2 provides the calibration of NO_2. The concentration of ozone used in the gas-phase titration (GPT) reaction can be measured using a photometer with a NIST-traceable calibration to validate the difference in concentrations for both NO_2 and NO.

Commercial NO_2 and NO calibrators have dynamic dilution manifolds with an internal ozone generator and photometer. The calibrator generates NO_2 concentrations by the technique of gas phase titration (GPT), in which standard ozone concentrations are reacted with excess NO. Nitric oxide standards are generated by difference, where standard ozone concentrations are reacted with excess NO and the change in NO concentration is measured.

7.2. Equipment Required

This procedure requires the following equipment:

1. NO_2 and NO calibrator
2. Zero air source
3. Compressed NO standard (refer to the manufacturer's User Manual for the calibrator)
4. Sampling lines (inert materials such as PTFE or FEP only)

Zero air can be generated either from compressed cylinders or from scrubbed ambient air. If ambient air is used, contaminants such as nitrogen dioxide and nitric oxide must be removed. The Model 405 nm will perform better if the zero air has humidity in the range 10-90 %RH. A set of DewLine™ Nafion® tubing is included with the Model 405 nm for installation between a dry gas supply and the instrument. The DewLine™ Nafion tubing introduces humidity to dry air or calibration standards without loss of NO_2 or NO.

7.3. Setup Check

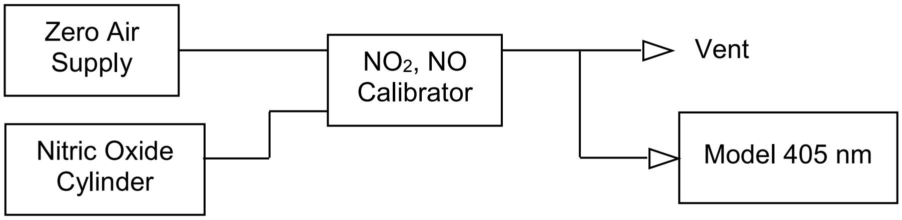
A visual inspection of the calibration setup should be performed before performing a calibration to verify that the setup is in proper order. All plumbing connections should be checked. Any obvious leaks should be fixed and the sampling tee and sampling lines should be checked for general cleanliness. For more information, refer to the manufacturer's User Manual for the calibrator.

7.4. Calibration Procedure

A multipoint calibration should be performed at least every 12 months. Within this calibration frequency, a multipoint calibration is advised whenever major disassembly of components is performed, or any time the zero or span checks give results outside of the acceptable limits.

7.4.1. Instrument Preparation

1. Turn on the Model 405 nm and allow it to stabilize for a minimum of 1 hour.
2. Enter the calibration menu (Main Menu /Cfg / Cal) and set the zero values to 0 and the slope values to 1.00 for both NO_2 and NO.
3. Connect the monitor to a sampling tee from the calibrator. The outlet of the calibrator must be vented to atmosphere so that pressure does not build up in the setup. Connection of the Model 405 nm directly to a pressurized output of any device can damage the monitor.
4. Verify that there is an overflow at the vent of the sampling tee.



7.4.2. Measurement of Zero Air

1. Verify that the zero-air supply is on and the calibrator is set to output zero air only.
2. Allow the Model 405 nm to sample zero air until the response is stable.
3. Record the average zero air responses.

7.4.3. Measurement of NO_2 and NO Standards

1. Allow the Model 405 nm to sample zero air until a stable response is measured and record the average responses.
2. To equilibrate the system, generate an NO concentration significantly higher than twice the concentration range of NO_2 that will be calibrated and allow the calibrator and equipment to equilibrate for at least 10 minutes.
3. The NO concentration should not be changed for the rest of the calibration.
4. Allow the Model 405 nm to sample the NO concentration standard until a stable response is measured and record the average responses.
5. Generate an ozone concentration at the high end of the concentration range of NO_2 that will be calibrated and allow the calibrator and equipment to equilibrate for at least 10 minutes.
6. Allow the Model 405 nm to sample the NO_2 and NO concentration standards until a stable response is measured and record the average responses.
7. Generate several other ozone concentrations to produce other concentrations of NO_2 and NO. At least 4 concentration standards are recommended over the range of interest.
8. For each concentration, record the responses of the Model 405 nm.
9. Turn off the ozone generator and continue to produce the NO concentration used during the calibration process and allow the calibrator and equipment to equilibrate for at least 10 minutes.
10. Verify that the standing NO concentration used during the calibration did not change more than a few ppb from the beginning of the calibration procedure. If the NO concentration is significantly different at the beginning and end of the calibration, then the calibration setup was not adequately equilibrated before collecting measurements.
11. Allow the Model 405 nm to sample zero air until a stable response is measured and record the average responses.

7.4.4. Calibration Curve

1. Calculate the measured NO_2 as the difference between the average zero response and the response at each concentration of NO_2. Any offset from background NO_2 released from the GPT chamber will be cancelled out this way.
2. Calculate the measured NO as the difference between the average standing NO concentration during the calibration and response at each concentration of NO.
3. Calculate the average NO_2 and NO measurement for zero air and use this zero for the calibration curve.
4. Plot the Model 405 nm measurements (y-axis) versus the corresponding standard concentrations (x-axis) for both the measured NO_2 and NO.
5. Fit the data to a straight line ($y = mx + b$) using the linear regression technique to determine the calibration relationships, where m=slope and b=intercept.
6. Determine if any points deviate significantly from the line, which is an indication of an error in determining the calibration curve. The error may

be due to the calibration setup or the monitor being calibrated. The most likely problems in the monitor are leaks, contamination of the DewLine^{TM} Nafion tubing, a contaminated valve, or contamination in the optical setup. See Section 10, the “Troubleshooting” section of this manual.

7. The inverse slope of the line (1/m) is the gain factor and the negative of the intercept (-b, in units of ppb) is the offset that need to be applied to the monitor response to calibrate it. If the intercept is outside of the range from -15 to 15 ppb or the slope is outside of the range from 0.90 to 1.10, this is an indication of a problem in the calibration setup or the monitor being calibrated. The most likely problems in the monitor are leaks, contamination of the DewLine^{TM} Nafion tubing, a contaminated valve, or contamination in the optical setup. See the “Troubleshooting” section of the manual (Section 10).
8. Enter the calibration menu (Main Menu / Cfg / Cal) in the instrument software and set the calibration parameters. Note that the offset (Z) parameter must be entered in units of ppb. If the calibration has been performed in other units, convert the offset to ppb before entering the value.

8. PERIODIC ZERO AND SPAN CHECKS

To ensure the quality of the monitor data, periodic zero and span checks are recommended. For continuous monitoring or measuring low NO_x levels (< 10 ppb), the zero offset should be tested at least once daily. For all zero or span checks the instrument should be turned on and allowed to warm up for at least 30 minutes.

8.1 Zero Offset Check

The electronic zeros for NO_2 and NO are tested by introducing NO_x-free air to the analyzer. The NO_x-free air can be generated from either (1) passing ambient air through a NO_x scrubber or (2) using zero grade air from a compressed cylinder or zero air generator.

1. To perform the zero offset test, attach either a NO_x scrubber or a flow of zero-grade air to the Model 405 nm inlet. This can be done by manually changing the inlet gas connection or by introducing the NO_x-free air to the inlet via a user-provided valve system. If zero-grade air is used, it is important to use an overflow tee as described in Section 7.4.1 above.

2. Upon addition of NO_x-free air, it is likely that there will be an initial perturbation in the system pressure which can cause the Pressure control Error Byte to appear on the LCD and serial output (See Section 9 for description of the Error Byte).

3. Allow the instrument to sample NO_x-free air for at least 5 to 10 minutes. Within the first minute or two, the pressure control should be re-established

and the Error byte should be cleared (00). Record and average both the NO and NO_2 channels for the last 3-5 minutes to obtain the new offset.

8.2. Span Check

Span checks should be performed using a commercial NO/NO_2 calibrator in a similar fashion as described in Section 7.4.3. Typically, a single point span check at ~ 80% of the expected NO_2 concentration range is adequate.

1. Connect the monitor to the calibrator output via a sampling tee. This can be done by manually changing the inlet gas connection or by a user-provided valve system. The outlet of the calibrator must be vented to atmosphere using an overflow tee so that pressure does not build up in the setup. Connection of the Model 405 nm directly to a pressurized output of any device can damage the monitor.
2. An initial high concentration of NO is added to the monitor using the calibrator. The NO concentration should be higher than twice the concentration range of NO_2 that will be calibrated. Allow the calibrator output to stabilize for at least 10 minutes. This will also allow the Model 405 nm pressure control to re-establish as described above for the Zero Offset Check. Allow the Model 405 nm to sample both the NO_2 and NO concentration standards until a stable response is measured and record the average responses.
3. Generate an ozone concentration in the calibrator at ~80% of the concentration range of NO_2 of interest and allow the calibrator output to stabilize again for at least 10 minutes. Again, allow the Model 405 nm to sample the NO_2 and NO concentration standards until a stable response is measured and record the average responses.

Average measurements from the zero check or span check should be within the instrument specifications. If this is not the case, a more thorough multipoint calibration in the NO_2 concentration range of interest is advised, following the steps as described above in the “Measurement of NO_2 and NO Standards” Section 7.4.3.

9. ERROR MESSAGES

When an Error occurs, an “E:” will appear on the bottom line of the LCD followed by the error byte. There is also a field in the serial data which holds the error byte. The error byte is represented by a hexadecimal code of two characters. There are no errors if the error byte in the serial data line is “00”. If there are no errors, the LCD will not display the “E:”.

9.1. Error Definitions

The following tables list all of the possible hexadecimal codes and their corresponding error definitions. The first table lists all of the errors if there were only one error while the second table lists all of the possible error combinations with their definitions.

Single Errors	
Error byte	**Definition**
00	No errors
08	Scrubber temp out of range. Temp is either > 113 degrees or < 110.
80	Pressure control out of range by > 1 mbar
04	Cell flow out of range (< 1200 or >1600)
40	Ozone flow out of range (<30 or >110)
02	Cell voltage out of range (<0.1V or >2.4V)
20	Ozone Generator voltage out of range (< 0.01V or >2.4V)

Combination Errors	
Error Byte	**Definition**
0A	Scrubber Temp and Cell Voltage
0C	Scrubber Temp and Cell Flow
0E	Scrubber Temp, Cell Flow, and Cell Voltage
22	Cell Voltage, and Ozone Generator Voltage
26	Cell Flow, Cell Voltage, and Ozone Generator Voltage
28	Scrubber Temp and Cell Voltage
24	Cell Flow and Cell Voltage
2A	Scrubber Temp, Cell Voltage, and Ozone Generator Voltage
2C	Scrubber Temp, Cell Flow, and Ozone Generator Voltage
2E	Scrubber Temp, Cell Flow, Cell Voltage, and Ozone Generator Voltage
42	Ozone Flow and Cell Voltage
46	Cell Flow, Ozone Flow, and Cell Voltage
48	Scrubber Temp and Ozone Flow
44	Cell Flow and Ozone Flow

4A	Scrubber Temp, Ozone Flow, and Cell Voltage
4C	Scrubber Temp, Cell Flow, and Ozone Flow
4E	Scrubber Temp, Cell Flow, Ozone Flow, and Cell Voltage
82	Pressure Control and Cell Voltage
84	Pressure Control and Cell Flow
86	Pressure Control, Cell Flow, and Cell Voltage
88	Scrubber Temp and Pressure Control
8A	Scrubber Temp, Pressure Control, and Cell Voltage
8C	Scrubber Temp, Pressure Control, and Cell Flow
8E	Scrubber Temp, Pressure Control, Cell Flow, and Cell Voltage
A0	Pressure Control and Ozone Generator Voltage
A2	Pressure Control, Cell Voltage, and Ozone Generator Voltage
A4	Pressure Control, Ozone Flow, and Ozone Generator Voltage
A6	Pressure Control, Ozone Flow, Cell Voltage, and Ozone Generator Voltage
A8	Scrubber Temp, Pressure Control, and Ozone Generator Voltage
AA	Scrubber Temp, Pressure Control, Cell Voltage, and Ozone Generator Voltage
AC	Scrubber Temp, Pressure Control, Cell Flow, and Ozone Generator Voltage
AE	Scrubber Temp, Pressure Control, Cell Flow,
C0	Pressure Control and Ozone Flow
C2	Pressure Control, Ozone Flow, and Cell Voltage
C4	Pressure Control, Cell Flow, and Ozone Flow
C6	Pressure Control, Cell Flow, Ozone Flow, and Cell Voltage
C8	Scrubber Temp, Pressure Control, and Ozone Flow
CA	Scrubber Temp, Pressure Control, Ozone Flow, and Cell Voltage
CC	Scrubber Temp, Pressure Control, Cell Flow, and Ozone Flow
CE	Scrubber Temp, Pressure Control, Cell Flow, Ozone Flow, and Cell Voltage
E0	Pressure Control, Ozone Flow, and Ozone Generator Voltage
E2	Pressure Control, Ozone Flow, Cell Voltage, and Ozone Generator Voltage
E4	Pressure Control, Cell Flow, Ozone Flow, Ozone Generator Voltage
E6	Pressure Control, Cell Flow, Ozone Flow, Cell Voltage, and Ozone Generator Voltage
E8	Scrubber Temp, Pressure Control, Ozone Flow, and Ozone Generator Voltage
EA	Scrubber Temp, Pressure Control, Ozone Flow, Cell Voltage, and Ozone Generator Voltage
EC	Scrubber Temp, Pressure Control, Cell Flow, Ozone Flow, and Ozone Generator Voltage
EE	Scrubber Temp, Pressure Control, Cell Flow, Ozone Flow, Cell Voltage and Ozone Generator Voltage

9.2. LCD Display of Error Byte

If errors are occurring, the LCD might read the following:

```
             NO2 = 34.8 ppb
  ---------------------------------------------
  LOG=193:0                     Tsc=112
  14:49           E:88       04/07/2017
```

where “88” is the error, which in this case means that the scrubber temperature is out of range and also the pressure control is out of range.

The alternate LCD view with error message is:

```
             NO2 = 34.8 ppb
  ---------------------------------------------
   CF=1525                       O3F=75
  T=35.2              E:88       P=985.7
```

If any errors are occurring, the user can scroll left or right during operation and view all of the errors that are occurring instead of trying to decipher the error code.
If the user scrolls during operation, where the error is “E88”, the LCD would read:

Errors
Scr Temp, Press Cntl

9.3. Serial Data Line

The error byte is located in the comma delimited serial output line after the scrubber temperature and before the date. For example:

```
67.4,44.2,111.6,30.3,980.6,1576,76.2,1.2743,1.0151,110.2,88,12/07/17,18:31:27,80
```

where:

NO2= 67.4 ppb
NO = 44.2 ppb
NOx= 111.6 ppb
Cell temperature = 30.3°C
Cell pressure = 980.6 mbar
Cell volumetric flow rate = 1576 cc/min
O3 volumetric flow rate = 76.2 cc/min
Sample photodiode voltage = 1.2743 volts
O3generator photodiode voltage = 1.0151 volts
Heated scrubber temperature = 110.2°C
Error Byte = 88 *(Pressure control and scrubber temperature are out of range)*
Date = July12, 2017
Time = 6:31:27 pm
Status = 80 *(Measuring $NO_2$and NO)*

10. TROUBLESHOOTING

If the instrument fails to operate correctly, common problems can be identified and corrected using the error messages described in Section 9. In addition, Table 10.1 provides troubleshooting information that can be used to diagnose the problem. If the problem cannot be easily corrected, please contact Customer Service at 2B Tech via our web ticketing software at:

https://twobtech.com/tech-support.html

Alternatively, you can email us at techsupport@twobtech.com or call us at +1(303) 273-0559. If we mutually determine that the instrument cannot be repaired onsite, we will provide you with a Return Authorization number and a short form to be filled out and returned to our Service Department along with the instrument.

The figures in Section 11 provide a "guided tour" of the Model 405 nm NO_2/NO/NO_x Monitor™ so that critical components and connectors may be easily identified. A list of serviceable parts is provided in Section 13 of this manual.

Table 10.1. Troubleshooting the NO_2/NO/NO_x Monitor for performance problems.

Problem/Symptom	Likely Cause	Corrective Action
Instrument does not turn on.	Power not connected properly or circuit breaker open.	Check external power connection for reverse polarity or a short and wait a few minutes for the thermal circuit breaker to reset.
	Power cable not connected to circuit board.	Remove top cover and disconnect and reconnect power cable to circuit board.
Instrument turns on then powers off.	Burned out air pump.	Remove top cover and unplug air pump. Turn instrument on; if it remains running, then the air pump motor is burned out and shorting. Replace air pump.
Display is blank or displays unreadable characters.	Bad connection of display to circuit board.	Remove top cover and reconnect display to circuit board. Check solder connections to display.
Cell temperature reads low by several 10's of degrees.	Absent or loose connection of temperature probe cable to circuit board.	Remove top cover and reattach connector to circuit board.

Problem/Symptom	Likely Cause	Corrective Action
Readings are noisy with standard deviations much greater than 3 ppb using 5-second averaging.	LED output is weak	Remove top cover and check LED connection to circuit board. Run LED Test from menu. If photodiode voltage is less than 0.5 V, replace LED.
	Excessive vibration	Provide additional vibration insulation for the instrument such as a foam pad.
	Flow path contaminated	Contact 2B Technologies for instructions if contamination is suspected.
Analog output is constant or does not track front display.	Cable not properly connected between analog output BNC and circuit board.	Remove top cover and reconnect cable between analog output and circuit board.
	Wrong scaling factor selected in Menu.	Check and reset analog output scaling factor in the Menu.
Select switch does not work.	Cable not properly connected between Select switch and circuit board.	Remove top cover and reconnect Select switch cable to circuit board.
Serial port does not work.	Cable not properly connected between serial 9-pin connector and circuit board.	Remove top cover and reconnect serial port cable to circuit board.
	Wrong serial cable used.	A “straight through” serial cable is provided. Some data collection devices require a “cross over” cable in which pins 1 and 3 are exchanged between the two ends of the cable. Use a “cross over cable or additional connector that switches pins 1 and 3.
	Wrong baud rate selected.	Make sure that the baud rate chosen in the Model 405 nm menu matches the baud rate setting of your data acquisition program.

Problem/Symptom	Likely Cause	Corrective Action
Required calibration parameters are outside the adjustable range when calibrated using a known calibration gas.	Flow path is contaminated.	Contact 2B Technologies for instructions if contamination is suspected.
	Solenoid valve is contaminated and not opening & closing properly.	Remove solenoid valve, rinse with methanol, dry with zero air, and replace.
	Air pump is not drawing sufficient flow.	As a first check, hold your finger over the air inlet to determine whether air is being drawn in. If there is flow, measure the flow rate by removing the top cover and attaching a **high conductance flow meter** (allows air to flow freely and does not cause significant pressure drop) to the exit port of the pump. Air flow should be greater than 1.4 L/min. If flow is lower, check for leaks. If there are no leaks, replace air pump.
Instrument has a large offset	Internal heated NO_2 scrubber is exhausted or contaminated.	Contact 2B Technologies about replacement of the internal heated NO_2 scrubber.
Instrument always reads close to zero for NO_2 concentrations.	Solenoid valve cable is not properly connected to circuit board.	Reattach solenoid valve cable to circuit board.
	Internal heated NO_2 scrubber is exhausted or contaminated.	Contact 2B Technologies about replacement of the internal heated NO_2 scrubber.

11. LABELED INSTRUMENT PHOTOS

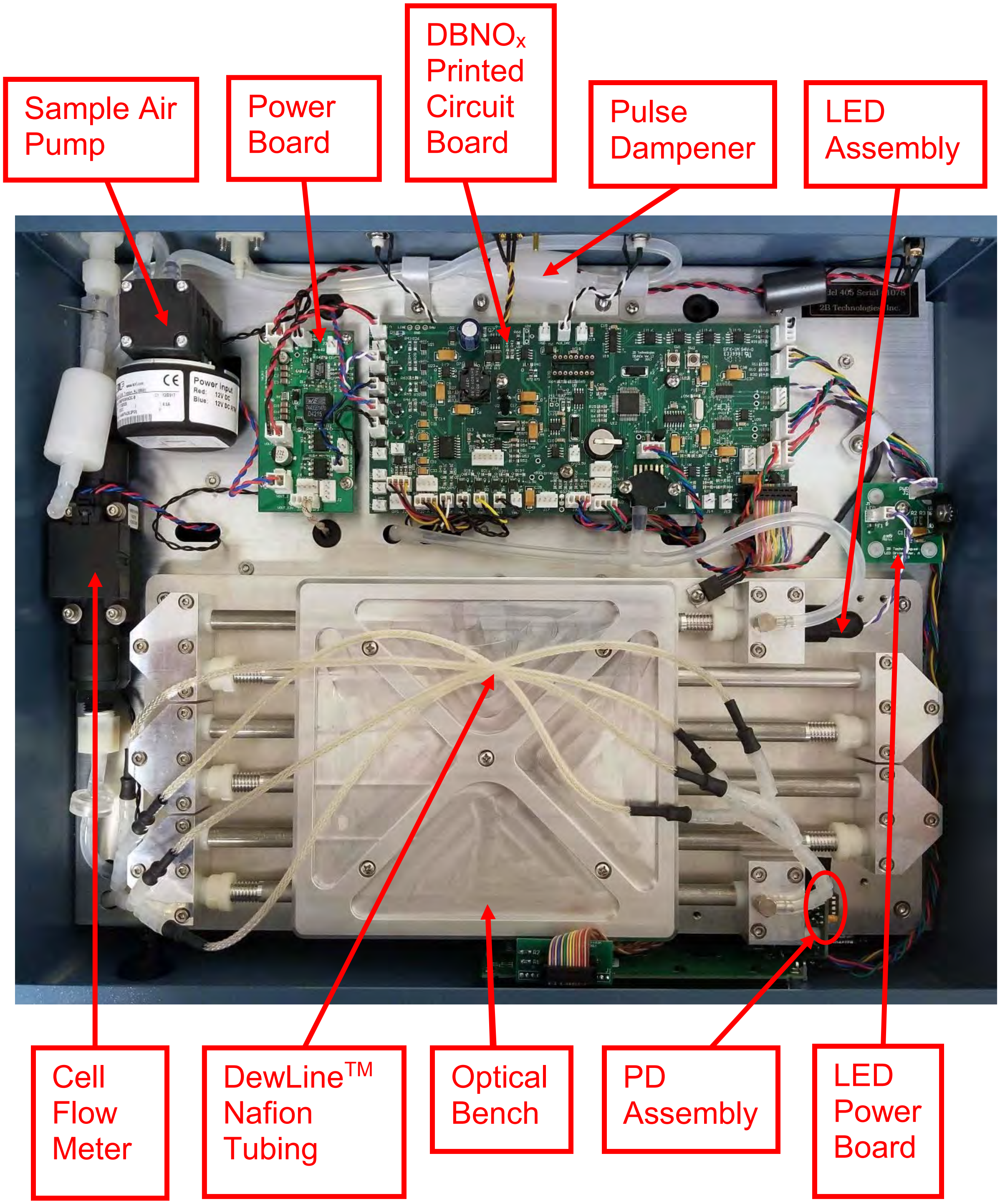


Figure 11.1. ***Top view of Model 405 nmNO_2/NO/NO_x Monitor with cover removed.***

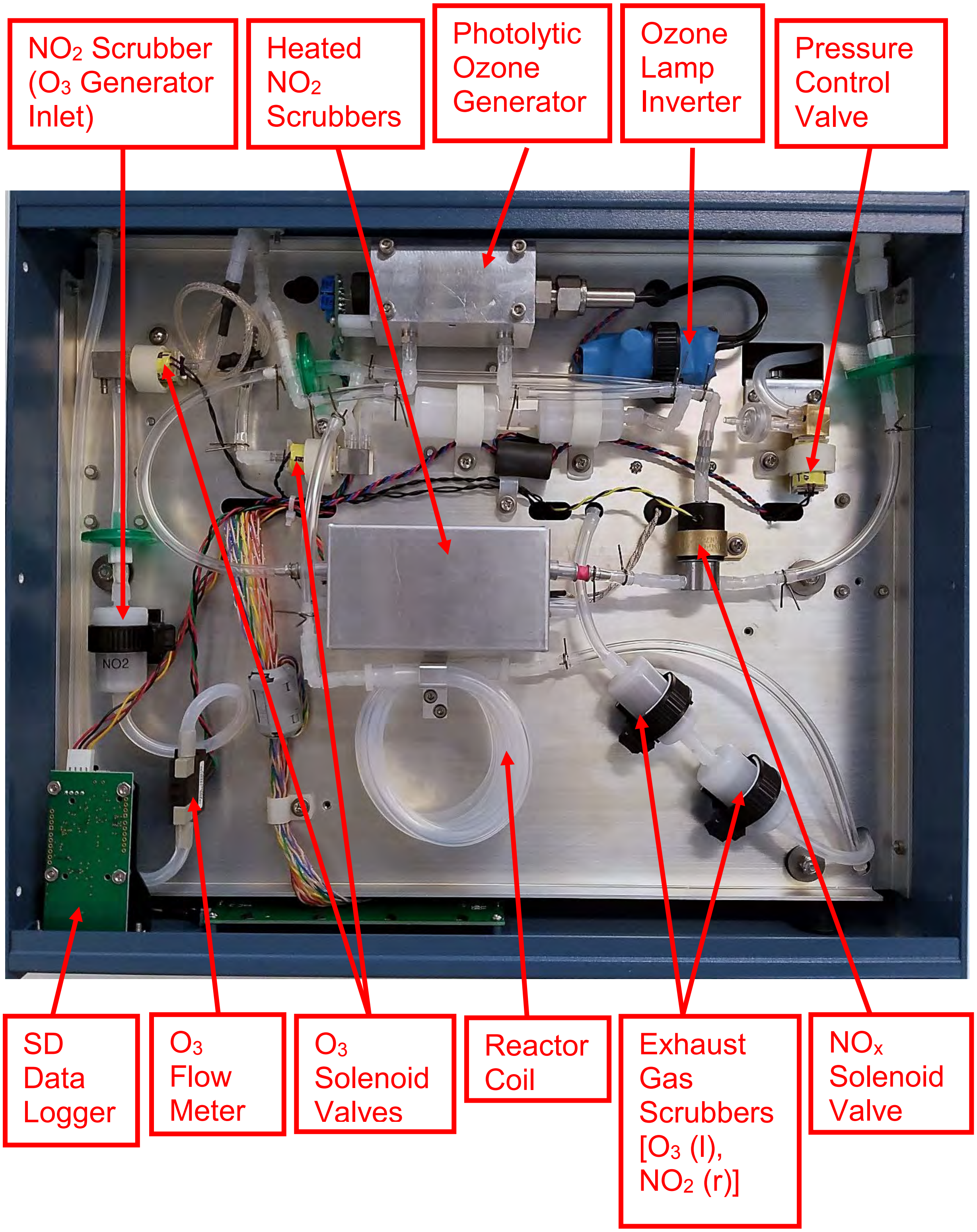


Figure 11.2. ***Bottom view of NO_2/NO/NO_x Monitor with cover removed.***

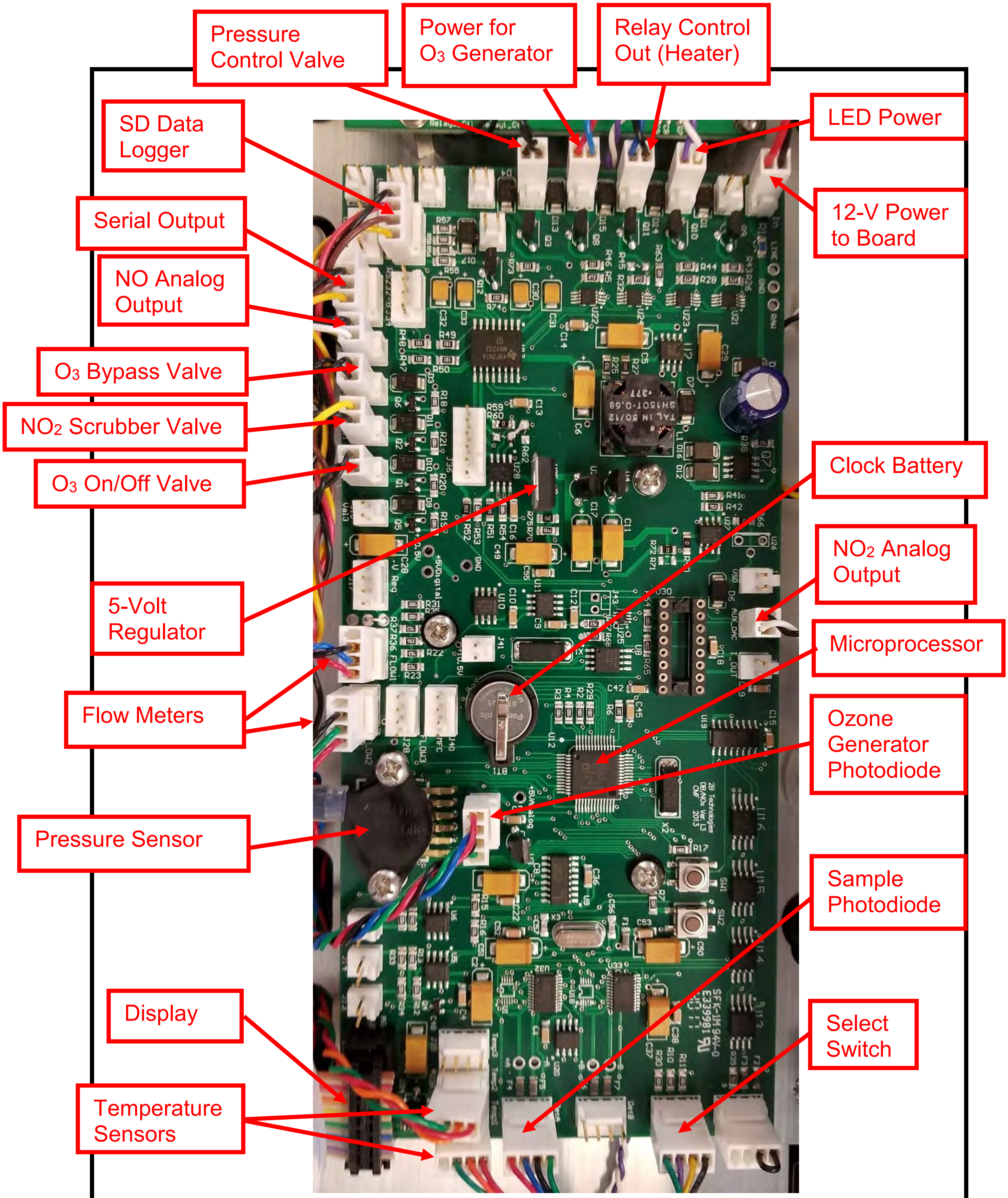


Figure 11.3. ***DBNOx Printed Circuit Board***

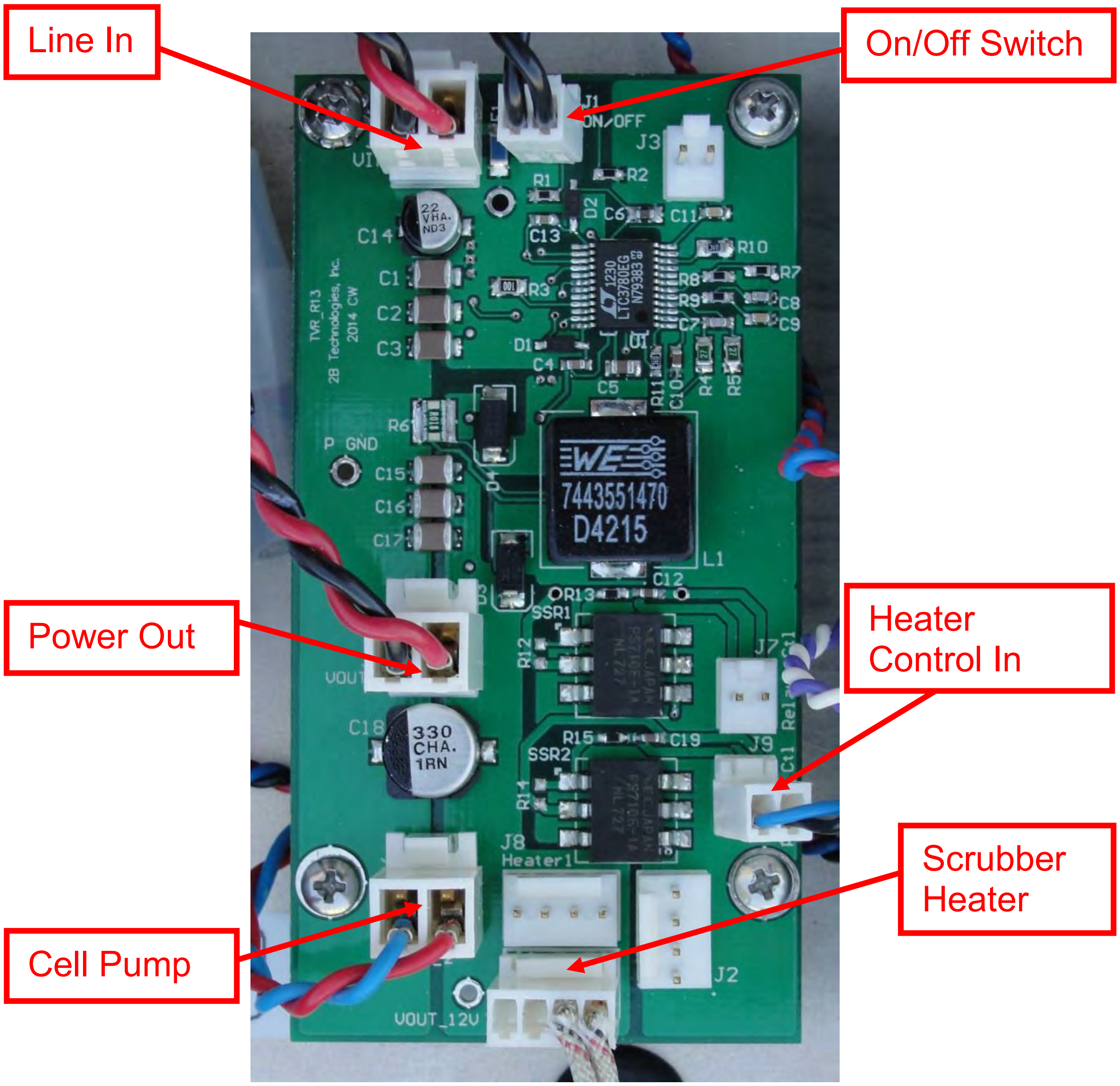


Figure 11.4. ***Power Board***

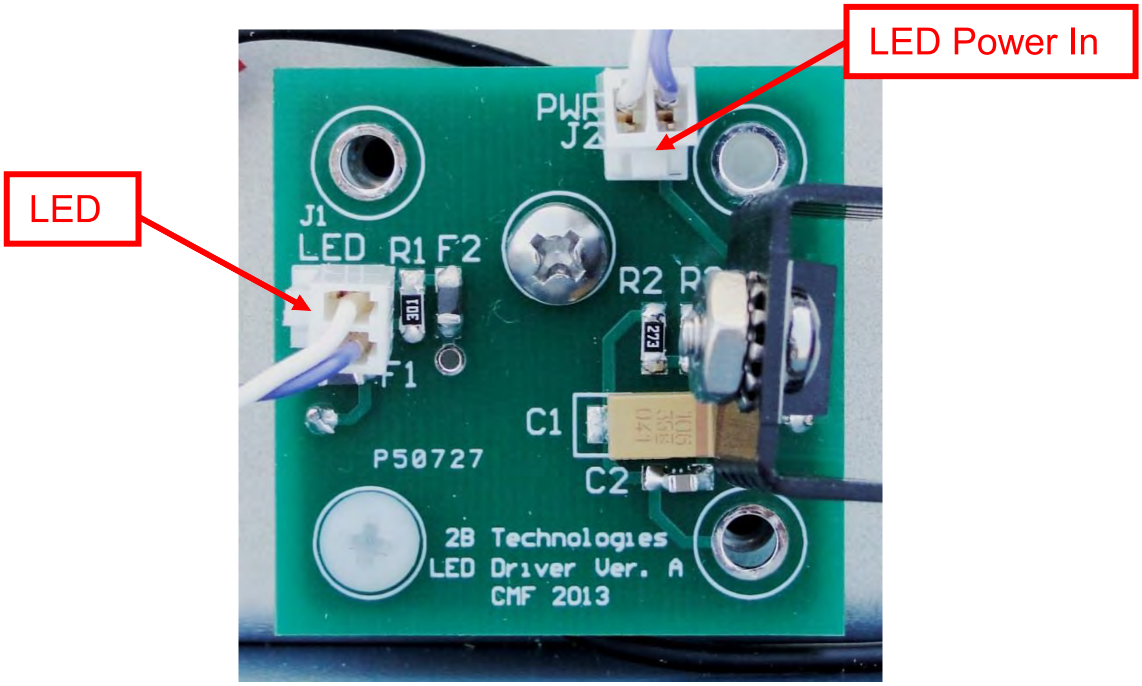


Figure 11.5. *LED Power Board*

Figure 11.6. ***Front and Back of Instrument***

12. WIRING CONNECTIONS

[For DBNOx board: Counter clockwise from upper right corner of Figure 11.3.]

Description	Circuit Board	Connection	Lead Colors
Line In	Main (DBNOx)	J12	Red/Black
LED Power Out	Main (DBNOx)	J22	Purple/White
Relay Control Out (Heater)	Main (DBNOx)	J23	Blue/Black
O_3 Generator Power	Main (DBNOx)	J21	Red/Blue
Pressure Regulator	Main (DBNOx)	J20	Black/Black
SD Data Logger	Main (DBNOx)	J35	Red/Yellow/Brown/Black
Serial RS-232	Main (DBNOx)	J26	Yellow/Brown/Black
NO Analog Output	Main (DBNOx)	J11	White/Black
Ozone Valve	Main (DBNOx)	J8	Black/Black
NO_2 Scrubber Valve	Main (DBNOx)	J19	Yellow/Black
Ozone On/Off Valve	Main (DBNOx)	J18	Black/Black
Cell Flow	Main (DBNOx)	J32	Red/Blue/Black
Ozone Flow	Main (DBNOx)	J9	Red/Blue or Green/Black
O_3 Generator Photodiode	Main (DBNOx)	J4	Red/Blue/Black/Green
LCD	Main (DBNOx)	J10	Rainbow Ribbon
Cell Temperature	Main (DBNOx)	J6	Red/Orange/Green
Scrubber Temperature	Main (DBNOx)	J38	Red/Orange/Green
Sample Photodiode	Main (DBNOx)	J29	Red/Blue/Black/Green
Select Switch	Main (DBNOx)	J5	Green/Purple/Yellow/Black
Power Jumper	Main (DBNOx)	J1	Black/Black
NO_2 Analog Output	Main (DBNOx)	J7	White/Black
On/Off Switch	Power	J1	Black/Black
Line In	Power	J4	Red/Black
Power Out	Power	J5	Red/Black
Sample Pump	Power	J6	Red/Blue
Relay Control In (Heater)	Power	J9	Blue/Black
Heater	Power	J10	White/White
LED	LED Driver	J1	Purple/White
Power In	LED Driver	J2	Purple/White

13. SPARE PARTS

The following list includes those parts of the Model 405 nm NO_2/NO/NO_x Monitor that are user serviceable.

Please see the 2B Technologies website for a full and updated list of parts and pricing for the Model 405 nm: https://twobtech.com/parts-online.html

Part Number	Description
NOXPUMP405	Sample pump
NOXVLV405	NOx solenoid valve (the Model 405 uses 3 of these)
OZVLV405	Ozone solenoid valve (the Model 405 uses 2 of these)
NOXDSP405	4-line LCD display and cable
LEDASSEMBLY405	LED assembly
PDASSEMBLY405	Photodiode assembly and cable
NOXBRD405	DBNOx printed circuit board
SCRBNO2INT405	NO_2 scrubber for ozone generator inlet
SCRBEXHST405	Exhaust scrubbers (two in series, O_3 and NO_2)
DEW	DewLine™ (Nafion tubing)
SERCABL	Serial port cable, straight-through, female-to-female (to computer)
CIGADAP	12 V DC cigarette lighter adapter
SDCARD	SD card (thin profile recommended for the Model 405 Monitor)
SDREADER	SD card reader
TEFTYG25	Teflon-lined Tygon® tubing (25 ft)
TEFTYG05	Teflon-lined Tygon® tubing (5 ft)
SILTUB05	Silicone tubing (5 ft)

14. SERVICE LOG

Date	Calibrated	Cleaned	New NO_2 Scrubber	New Pump	New LED	Other

Date	Calibrated	Cleaned	New NO_2 Scrubber	New Pump	New LED	Other

Appendix A: Using the 2B Technologies Display and Graphing Software

Introduction

2B Data Display© is an easy way to display and save data from your serial or USB connection.

With easy one-click operations, data are read from your instrument and displayed on an extremely versatile chart. Two items, such as Ozone and Temperature, can be displayed simultaneously on the chart with multiple zoom levels. Data are automatically saved to a .txt file and can optionally be saved to a .CSV file to be read in Excel. Saved data can be restored for later viewing and analyzing on the chart. By requesting an account with 2B Technologies, you can upload your data and view it on a Google Earth overlay.

Downloading the Software

Go to https://twobtech.com/downloads.html and select the Software tab. Click the link for "2B Tech Display and Download Software." Follow the instructions, doing the two installations if needed and choosing to save the "setup.exe" file. Double-click the setup.exe download to launch the 2B Data Display application.

Connecting Devices

Connect to a 2B Technologies Monitor

1. Select the device you are connecting to from Settings: Select Device...
2. Click OK.
3. Select the Connection you will be using from Settings: Connection...
   Choose the settings as follows:
   a) Port:
      - The default port is "COM1" for computers with a serial port.
      - If using a USB connection, check for the correct port in the "Device Manager" under "Ports" located in: Control Panel : System : Device Manager.
      - If using a USB to Serial adapter, check for the correct port the same as for a USB connection and look for the name of the adapter (e.g., Belkin, Prolific, or other USB to Serial adapter manufacturers).

   b) Baud Rate: The Default baud rate is 2400. Check your Monitor's settings in the "Cfg / I/O" menu and match the software with the monitor's setting. Note that for the USB port of a Monitor, the baud rate must match the baud rate of the Monitor at the Monitor's startup.
   c) Parity: None
   d) Data Bits: 8

   e) Stop Bits: One
4. Click Start button in the Instrument Data Capture section in the upper left corner of the main screen.
   a) The "Save As" window will appear. A default file name will appear which is made of the date and time. You may change the filename and change where it is saved if you wish.
   b) Click the "Save" button. This will start the data capture software and data will fill into the chart as they are transmitted from the device.
   c) The red OFF text will change to green ON text. The text: Waiting for data… will appear until data arrives from the instrument. If the instrument measurement frequency is set to 2 seconds, for example, you will see a data point every 2 seconds. Averaging frequencies can be set to different values in the Avg submenu on the instrument.

Connect to Weather Station (Davis Vantage Pro)

1. Be sure the weather station is physically connected to the USB port or Serial port of the computer.
2. Select the COM port for the weather station from *Settings : Weather Connection Settings…*
3. Select "Retrieve Weather Data" from the "Weather Link" menu. A window will appear and the software will try to retrieve the weather station data. If the connection is good, weather data will be displayed in the window. If not, an error message will appear. Try a different com port if the error message appears. You may move this window so it is out of the way or you may close it. The weather data is updated every 5 seconds.
   - Since the Monitor and the Weather Station both use COM ports, you may have to unplug one of the USB adapters from the PC to determine which device is using which COM port.
4. To bring up the window again if you have closed it, select "Display Weather Data."

Viewing Data

The Data Grid Tab

1. Make sure the application is connected to a device or that you have opened a previously saved data file.
2. Click the *Data Grid* tab on the right side of the screen.
3. The data lines received from your instrument will be listed in a grid with the latest point at the top.
4. The header contains the device specific variables (e.g., Ozone, Cell Temp...). Log Number is always listed even if your instrument is not set to log.

The Charts Tab

1. Make sure the application is connected to a device or you have opened a previously saved data file.
2. Click the *Charts* tab on the right side of the screen.
3. Select which data items to display from the drop down windows "Data 1" and "Data 2."

4. The data points will appear in a graph window in the middle of the screen.
5. Adjust the zoom level by pressing the + or – buttons under the *Settings* button (upper right side of screen).
6. Adjust the Y scale or set the *Auto Range* feature by pressing the *Settings* button
    a. Check the *Auto Range* box to use autoscaling
    b. Uncheck the *Auto Range* box to manually set Y max and Y min for the Data 1 and Data 2 fields.

The Buffer Tab

- Selecting the Buffer tab brings up a buffer window, similar to Tera Term or HyperTerminal, where all data from the serial port are displayed.
- From this tab, the user can also send commands through the serial port by typing on the keyboard. This is only applicable if the device that is connected accepts serial commands.
- This buffer window can also be used for troubleshooting for instances when: the baud rate, device, or serial port is unknown. For example, if the status bar in the "Instrument Data Capture area states "Receiving…" and no data appear in the Data Grid or the Charts, click on the Buffer tab to view the serial data. If the correct device is not selected, no data will be displayed in the Data Grid or the Charts, but data will be displayed in the Buffer window.

Saving Data

Saving Data to a .txt File

1. Click the *Start* button in the Instrument Data Section to begin collecting data from the instrument.
2. A window will pop up to prompt for the name and location of the file.
3. Click Save to begin the data collection.
4. All data read from the ozone monitor through the COM port are written to the .txt file in real time until *Stop* is clicked.

Saving Data to a .CSV or an Excel File

NOTE: Weather data are NOT saved to the .txt file. In order to save weather data, be sure to save a .CSV file after *Stop* is clicked.

1. After collecting data, click the *Stop* button in the Instrument Data Capture Section on the main screen.
2. A window will pop up to ask you if you would like to save to a CSV file as well. Click *Yes*.
3. A default name appears from the date and time of the data capture. You may change the name and path of the file if you wish.
4. Click on the *Save* button.

Opening Files

1. To open a file, click *Open* from the *File* menu.
2. Navigate to the folder where the file was stored.
3. Select either the .txt file or the excel file and press *Open*.
    1. NOTE: To view weather data, you must open the corresponding .CSV file.

4. Choose the correct device associated with the file.
    a. If you are unsure, open the file in a text editor or Excel to determine which device.

Serial Commands

The menu commands are the same as given elsewhere in this manual.