TÜV RHEINLAND ENERGY GMBH

Deutsche
Akkreditierungsstelle
D-PL-11120-02-00

Report on the performance test of the N500 ambient air quality measuring system manufactured by Teledyne API for the components NO, NO_2 and NOx

TÜV-Report: 936/21251100/A
Cologne, 30 July 2021

www.umwelt-tuv.de

tre-service@de.tuv.com

TÜV Rheinland Energy GmbH and its Ambient Air Quality department in particular
is accredited for the following activities:

- Determination of emissions and ambient air quality affected by air pollutants and odorous substances;
- Inspection of correct installation, functionality and calibration of continuous emission monitoring systems including systems for data evaluation and remote monitoring of emissions,
- Measurements in combustion chambers;
- Performance testing of measuring systems for continuous monitoring of emissions and air quality as well as electronic data evaluation and remote monitoring systems for emissions
- Determination of the stack height and air quality forecasts for hazardous and odorous substances;
- Determination of emissions and ambient air quality affected by noise and vibration, determination of
- sound power levels and noise measurements at wind turbines;

according to EN ISO/IEC 17025.

The accreditation has the DAkkS registration number: D-PL-11120-02-00
and covers the scope specified in the annex to the certificate.

TÜV Rheinland Energy GmbH
D - 51105 Köln, Am Grauen Stein,
Tel: + 49 (0) 221 806-5200, fax: 0221 806-1349

Blank page

Report on the performance test of the N500 ambient air quality measuring system manufactured by Teledyne API for the components NO, NO2 and NOx

AMS designation: N500

Manufacturer: Teledyne API
9970 Carrol Canyon Road
San Diego, California, 92131
USA

Test period: September 2020 to July 2021

Date of report: 30 July 2021

Report Number: 936/21251100/A

Editor: Dipl.-Ing. Martin Schneider
Phone: +49 221 806-1614
martin.schneider@de.tuv.com

Scope of the report:

Report:		188	Pages
Manual	pages	189	
Manual	with	104	Pages
Total		293	Pages

Blank page

Table of contents

List of tables

List of figures

1. Summary and certification proposal

1.1 Summary Overview

On behalf of Teledyne API, TÜV Rheinland Energy GmbH carried out the performance test of the N500 AMS for the components NO, NO_2 and NOx. 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 November 2012
- Guide to the Demonstration of Equivalence of Ambient Air Monitoring Methods of January 2010

The N500 measuring system determines the components NO, NO_2 and NOx directly by means of CAPS (Cavity-Attenuated Phase Shift) spectroscopy and conversion by gas phase titration. Thus, the measuring principle does not correspond to the to chemiluminscence as the EU reference method. Annex 1 presents the field test results of comparison measurements with the reference method for NOx (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 instrument's measuring principle determines NO_2 and NO directly. The output NOx value as the sum of NO and NO_2 is always calculated. 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 carried out in the laboratory of TÜV Rheinland Energy GmbH and during a three-month field test near Cologne. The measuring ranges are indicated below:

Table 1: Measuring ranges tested

Measured component	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:

N500 for NO, NO_2 and NOx

Manufacturer:

Teledyne API, San Diego, USA

Field of application:

For the continuous determination of ambient air concentrations of nitrogen oxides in stationary use.

Measuring ranges during performance testing:

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

Software version:

Rev. 1.6.0

Restrictions:

None

Note:

1. This report on the performance test is available online at www.qal1.de.
2. 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. 936/21251100/A of 30 July 2021

Blank page

1.3 Summary report on test results

Performance criterion	Requirement	Test result	Satis-fied	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	38
7.3.2 Calibration inlet	The measuring system may have a test gas inlet separate from the sample gas inlet.	The measuring system has a test gas inlet separate from the sample gas inlet at the instrument back.	yes	39
7.3.3 Easy maintenance	It should be possible to carry out maintenance work from the outside without major effort.	Maintenance takes reasonable effort and is possible with standard tools from the outside.	yes	40
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	41
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	42
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	43
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 secured against unintended and unauthorised adjustment of instrument parameters by way of a password.	yes	44
7.3.8 Data output	The output signals shall be provided digitally and/or as analogue signals.	The measuring signals are offered in analogue (0 – 20 mA, 4 – 20 mA or 0 – 1V,0 – 5 V, 0 – 10 V) and digital (via TCP/IP, RS 232, USB).	yes	45
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	46

Performance criterion	Requirement	Test result	Satis-fied	Page
7.3.10 Data transmission protocol	Shall meet the requirements stipulated in Table 1 of VDI Guideline 4202 part 1.	The measuring system has an installed Modbus "Bavaria/Hesse" (Bayern/Hessen) transmission protocol as standard. Measured and status signals are transmitted correctly. The configuration is listed in the manual in Appendix A.2	yes	47
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. Other measuring ranges up to a maximum of 0 – 1 are possible. The measuring system's upper limit of measurement exceeds the upper limit of the certification range in each case.	yes	48
7.3.12 Negative output signals	May not be suppressed (live zero).	The measuring system also provides negative output signals.	yes	49
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.	The measuring system is in fault-free operational readiness when the voltage returns and automatically resumes measuring operation after a warm-up phase.	yes	50
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	51
7.3.15 Switch-over	Switch-over between measurement and functional check and/or calibration shall be possible telemetrically.	In principle, all necessary work for function control can be monitored and controlled directly on the unit or by telemetric remote control.	yes	52
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	53

Performance criterion	Requirement	Test result	Satis-fied	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	54
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	55
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	79
7.5.2 Location for the field test	The monitoring station for the field test is to be chosen according to the requirements of 39th 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. Details on the location of the measuring station are given in chapter 4.3.	yes	80
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	81
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 during the laboratory test 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 determined response time for unit 1 was 24 sec for NO and 24 sec for NO2. For unit 2 it was 25 sec for NO and 25 sec for NO2.	yes	90
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 0.06 nmol/mol for instrument 1; for instrument 2, it was -0.27 nmol/mol. For NO, the value for the short-term drift at span point was 2.36 nmol/mol for instrument 1; for instrument 2, it was 1.11 nmol/mol. For NO2, the value for the short-term drift at zero point was -0.03 nmol/mol for instrument 1; for instrument 2, it was -0.26 nmol/mol. For NO2, the value for the short-term drift at span point was 2.76 nmol/mol for instrument 1; for instrument 2, it was 2.72 nmol/mol.	yes	95
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 span point it shall not exceed 3.0 nmol/mol.	For NO, the value for the repeatability standard deviation at zero point was 0.13 nmol/mol for instrument 1; for instrument 2 it was 0.13 nmol/mol. Repeatability standard deviation at span point was 1.63 nmol/mol for instrument 1 and 1.34 nmol/mol for instrument 2. For NO2, the value for the repeatability standard deviation at zero point was 0.00 nmol/mol for instrument 1 and 0.11 nmol/mol for instrument 2. Repeatability standard deviation at span point was 0.08 nmol/mol for instrument 1 and 0.08 nmol/mol for instrument 2.	yes	101

Performance criterion	Requirement	Test result	Satis-fied	Page
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 -0.60 nmol/mol at zero point and no more than 1.72% of the rated value for concentrations above zero. The deviation from the linear regression line for instrument 2 is -0.60 nmol/mol at zero point and no more than 2.24% of the rated value for concentrations above zero. Component NO2 The deviation from the linear regression line for instrument 1 is -0.16 nmol/mol at zero point and no more than 0.85% of the rated value for concentrations above zero. The deviation from the linear regression line for instrument 2 is -0.49 nmol/mol at zero point and no more than 0.72% of the rated value for concentrations above zero.	yes	105
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 0.23 nmol/mol/kPa for instrument 1; for instrument 2 it was 0.17 nmol/mol/kPa. For NO2, the sensitivity coefficient to sample gas pressure was 0.10 nmol/mol/kPa for instrument 1; for instrument 2 it was 0.08 nmol/mol/kPa.	yes	112

Performance criterion	Requirement	Test result	Satis-fied	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 0.09 nmol/mol/K for NO; for NO2, it was 0.11 nmol/mol/K. For instrument 2, the sensitivity coefficient to sample gas temperature was 0.01 nmol/mol/K for NO; for NO2, it was 0.01 nmol/mol/K.	yes	115
8.4.9 Sensitivity coefficient to surrounding temperature	The sensitivity coefficient to the surrounding 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 0.952 nmol/mol/K for instrument 1 and 0.451 nmol/mol/K for instrument 2. For NO2, this would be 0.231 nmol/mol/K for instrument 1 and 0.241 nmol/mol/K for instrument 2.	yes	118
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 exceed the value of 0.3 nmol/mol/V specified in standard EN 14211. For the purpose of the uncertainty calculation, the largest value 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 0.02 nmol/mol/V for instrument 1 and 0.01 nmol/mol/V for instrument 2.	yes	122

Performance criterion	**Requirement**	**Test result**	**Satis-fied**	**Page**
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.	For NO at zero point the result for the interference were 0.00 nmol/mol (AMS 1) and -0.60 nmol/mol (AMS 2) for H2O, 0.40 nmol/mol (AMS 1) and 0.40 nmol/mol (AMS 2) for CO2 and finally 0.60 nmol/mol (AMS 1) and 1.00 nmol/mol (AMS 2) for NH3. For NO2 at zero point the result for the interference were 0.27 nmol/mol (AMS 1) and 0.00 nmol/mol (AMS 2) for H2O, 0.00 nmol/mol (AMS 1) and -0.21 nmol/mol (AMS 2) for CO2 and finally 0.00 nmol/mol (AMS 1) and -0.16 nmol/mol (AMS 2) for NH3. The following results were obtained for the cross-sensitivity at the limit value ct: NO: 0.40 nmol/mol for instrument 1 and 1.60 nmol/mol for instrument 2; H2O: 1.80 nmol/mol for instrument 1 and 0.80 nmol/mol for instrument 2; CO2 and 1.20 nmol/mol for instrument 1 and 1.40 nmol/mol at NH3. The following results were obtained for the cross-sensitivity at the limit value ct: NO2: 0.33 nmol/mol for instrument 1 and 0.22 nmol/mol for instrument 2; H2O: 0.70 nmol/mol for instrument 1 and 0.76 nmol/mol for instrument 2; CO2 and 1.09 nmol/mol for instrument 1 and 0.98 nmol/mol at NH3.	yes	126
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	130

Performance criterion	Requirement	Test result	Satis-fied	Page
8.4.13 Difference sample/calibration port	The difference between the sample and calibration ports shall not exceed 1%.	The performance criterion specified by standard EN 14211 is fully satisfied.	yes	134
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	136
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 1.9 s.	yes	136
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 $Dl_{,z}$ for NO was at -0.92 nmol/mol for instrument 1 and 1.08 nmol/mol for instrument 2. Maximum long-term drift at span point $Dl_{,s}$ for NO was at 0.93% for instrument 1 and 1.02% for instrument 2. Maximum long-term drift at zero point $Dl_{,z}$ for NO2 was at 0.75 nmol/mol for instrument 1 and 0.87 nmol/mol for instrument 2. Maximum long-term drift at span point $Dl_{,s}$ for NO2 was at 2.29% for instrument 1 and 2.05% for instrument 2.	yes	140
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 must be changed depending on the dust load at the measuring location. EN 14211 requires checking of zero and span points at least once every two weeks.	yes	149
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 3.67% as a percentage of the mean value over the three-month field test period. Thus, the requirements of EN 14211 are satisfied.	yes	145
8.5.7 Period of availability of the analyser	Availability of the analyser shall be at least 90%.	The availability is at 100%. Thus, the requirement of EN 14211 is satisfied.	yes	150

2. Task definition

2.1 Nature of the test

On behalf of the company Teledyne API, a performance test for the measuring system N500 was carried out by TÜV Rheinland Energy GmbH. 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 – 1 200	µg/m³
Nitrogen dioxide	0 - 500	µg/m³

The N500 measuring system measures the components NO, NO_2 and NOx by means of direct UV absorption.

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 Guideline 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 November 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 N500 analyser is an optical absorption spectrometer that can directly measure NO_2 using the Cavity Attenuated Phase Shift (CAPS) method. The CAPS method uses blue UV light from an LED with a wavelength of 405 nm, a measuring cell with highly reflective mirrors on both sides to extend the optical path, and a vacuum photo detector. All components are integrated in the optical measuring cell, which is located in a thermostated area. This area is heated to 45 °C to prevent moisture on the mirrors and the effects of fluctuating ambient temperatures.
The NO_2 is determined directly by optical absorption. This measurement principle is laid down in Lambert-Beer's law. The absorption (light loss) is directly proportional to the light path and the concentration of the absorbing gas.

$$A = \varepsilon l c$$

(A = absorption, ε = molar absorption coefficient, l = light path length, c = concentration)

Ultraviolet light from the modulating LED is sent into the cell behind mirror A. The light intensity is then measured by the detector, which itself is modulated with a slightly different frequency. The detector sits behind mirror B and measures an exponentially increasing signal when the LED is switched on. When the LED is switched off, there is also a drop in intensity. Since both mirrors are highly reflective at 405 nm (the highest absorption range of NO_2), the light needs a certain time to reach the maximum in the absence of the absorbing gas. In the presence of NO_2, the path of light is significantly shortened. This has two effects on the light intensity measured by the detector:

- The maximum of light is smaller
- The maximum of light is reached earlier.

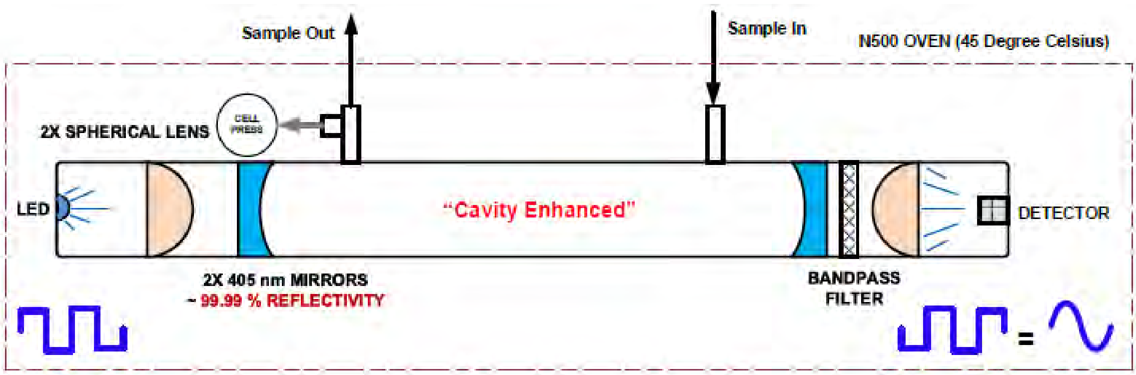


Figure 1: N500 optical absorption cell

This measures a phase shift to the modulating LED. The phase shift is greatest at zero gas and decreases when NO_2 is present.

Both the LED and the detector are modulated to produce the measured signal at a much lower frequency (corresponding to the difference between the modulating frequencies). This signal is then easier for the system's hardware to process.

The system transfers the phase shift into a concentration. Using the CAPS method, the phase shift remains constant for each concentration, even if the LED ages and loses intensity over time.

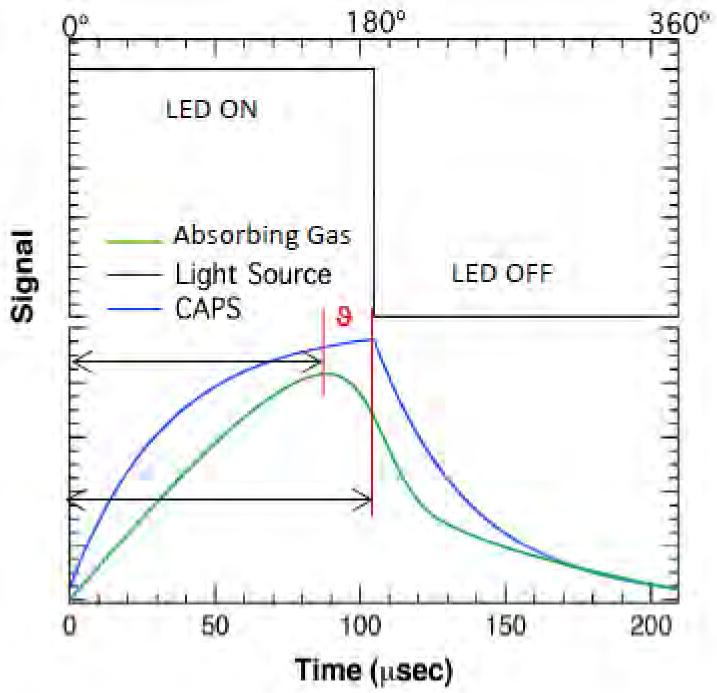


Figure 2: Phase shift of increased NO_2 concentration

An internal vacuum pump, located downstream from the rest of the instrument's components, draws test gas through the instrument's pneumatic connections. The flow rate is controlled by a flow limiter upstream of the sensor.

After the test gas has passed through a series of filtering and conditioning components, a sensor determines the NO_2 reading. The test gas is titrated alternately with high concentrations of ozone. A sensor then measures a second, higher NO_2 value (NO_X mode). The NOx concentration and the NO concentration are derived from this value.

In summary, the N500 analyser measures NO_2 first directly by optical absorption to obtain an actual reading of the NO_2 concentration. Then a precisely timed pulse rate is used to mix the sample with a high concentration of O_3 to generate NO_X . The software then subtracts the NO_2 concentration from the output NO_x concentration to calculate a reading for NO. At the NO concentration, compensation is then made for the titration efficiency, which is then added to the measured NO_2 value to produce the corrected NO_X reading.

3.2 AMS scope and set-up

The main components of the N500 analyser are: an optical cell, a pair of highly reflective mirrors at 405 nm, a light emitting diode (LED) light source and a vacuum photodiode detector.

The LED is behind a mirror at one end of the cell, and the detector is behind the other mirror at the opposite end of the cell. The light emitting diode sends light pulses in the ultraviolet spectrum into the measuring cell. The light is reflected by the mirrors over and over again, creating a very long path length. This long path of light extends the "lifetime" of the photon using a data acquisition system timed to the measurement. Together with an algorithm, the measured absorption is converted into a phase offset from which the NO_2 concentration is calculated.

Figure 3: N500 Analysers

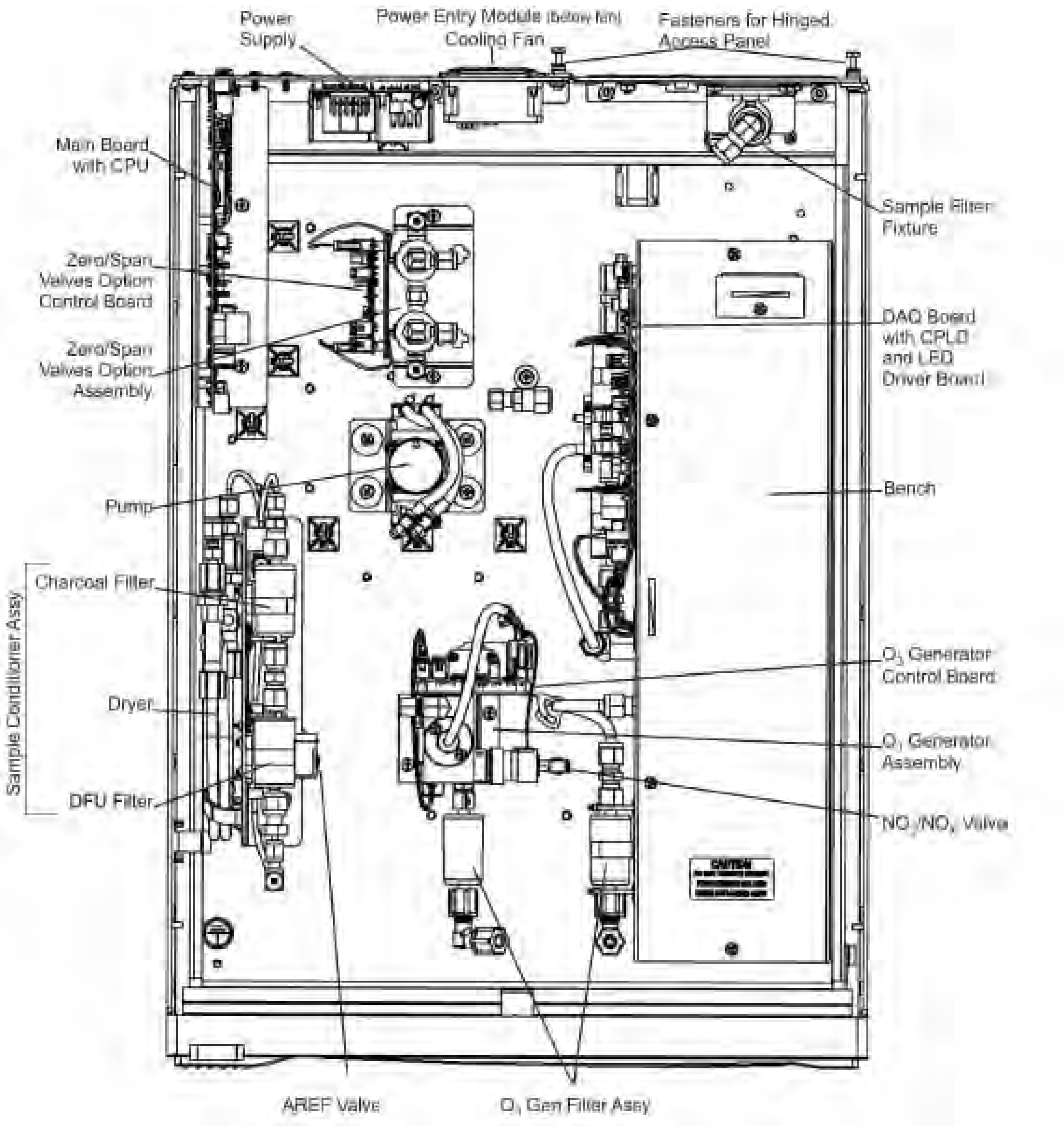


Figure 4: Internal components of the model N500

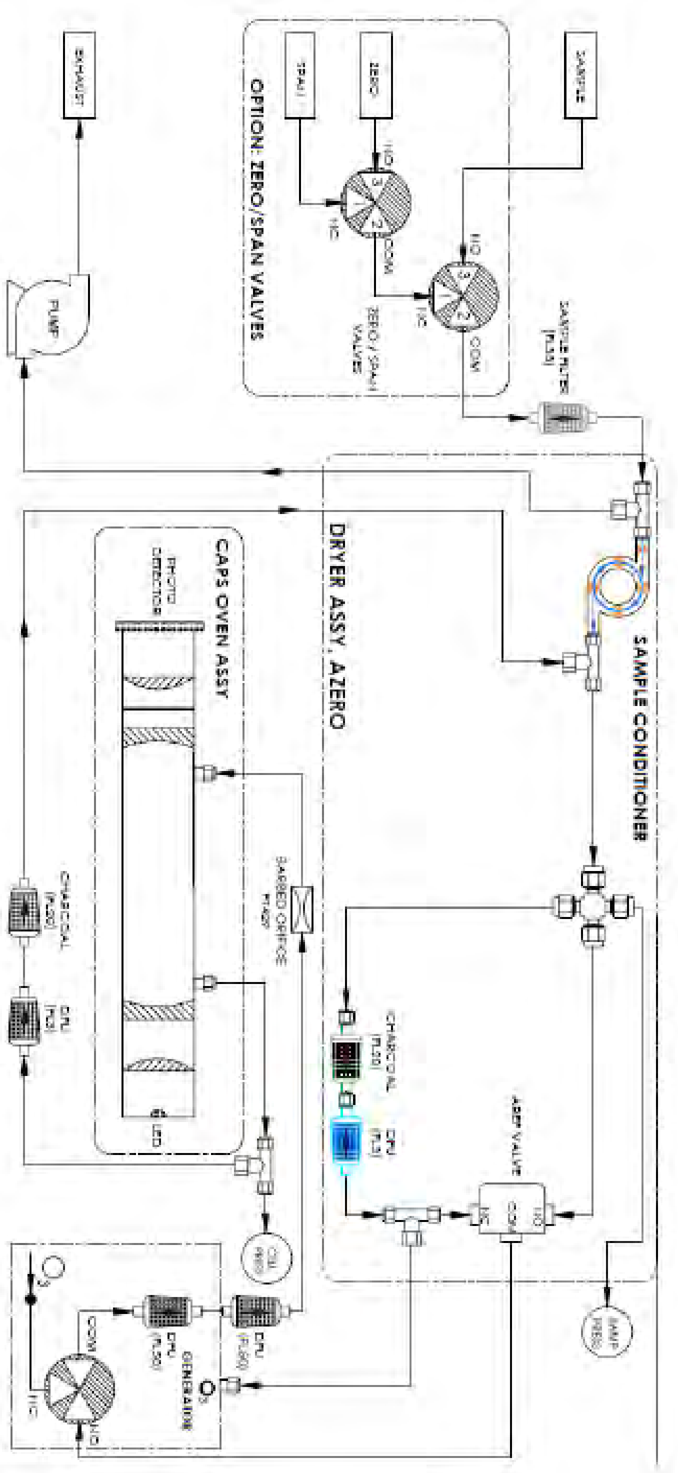


Figure 5: N500 pneumatic flow diagram

Table 2 contains a list of important technical characteristics of the N500.

Table 2: N500 system technical data (manufacturer's data)

Measured range:	Maximum 0 - 1 ppm for NO_2 Maximum 0 - 1 ppm for NO
Units:	ppb, ppm, mg/m³ or µg/m³
Measured compounds:	NO, NO_2 and NO_x
Sample flow rate	~1.0 l/min (during the test)
Outputs:	• Ethernet TCP/IP • Serial interface, RS232 or RS 485 • 0 – 5/10 Volt analogue • 4 – 20 mA analogue • USB
Input voltage:	230 V or 115 V 50Hz or 60 Hz
Power:	110 W; 190 W max.
Dimension (l x w x h)	597 x 732 x 178 mm / ~ 15 kg

3.3 AMS adjustment

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

The N500 analyser firmware processes sample concentration data via a programmed adaptive filter. During operation, the firmware can automatically switch between two different temporal filter lengths depending on the conditions. When measuring stable concentrations, the firmware calculates an average over the last measurements by default. This ensures reliable measurement results. If the filter detects rapid changes in concentration, it reduces the averaging time to allow the analyser to respond more quickly. The adaptive filter is always active and can neither be adjusted nor deactivated by the user.

4. Test programme

4.1 General remarks

Two identical N500 instruments with the following serial numbers were submitted to performance testing:

Instrument 1: SN 65 and
Instrument 2: SN 76

The tests were performed with software version 1.6.0.

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.

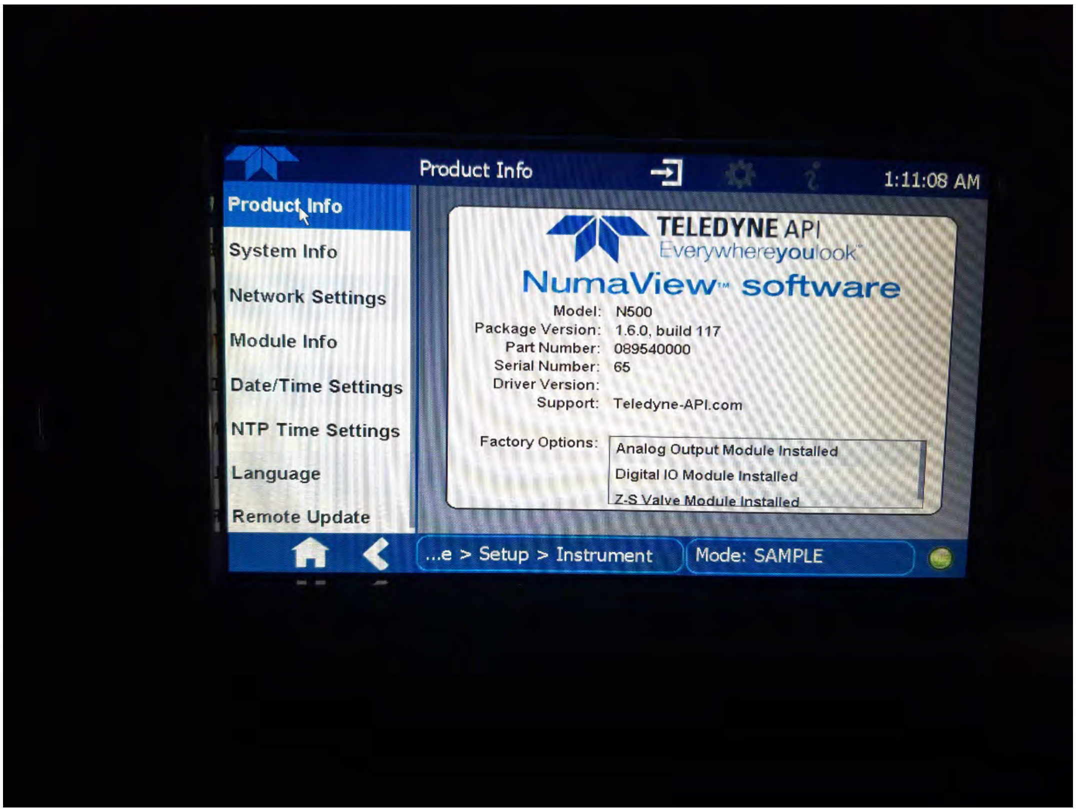


Figure 6: Software version of the N500 tested instruments

4.2 Laboratory test

The laboratory test was carried out with two identical instruments, type N500, with serial numbers S/N: 65 and SN: 76. 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 work according to the EU standard reference method (chemiluminescence), but alternately analyses NO_2 and NO directly due to its measuring principle (CAPS). The output for the NOx 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 summarize the results of the laboratory tests.

4.3 Field test

The field test in accordance with EN 14211 and VDI 4202-1 was carried out with two identical measuring systems of type N500 from 09 November 2020 to 15 February 2021. Subsequently, the field measurements were continued until 01 July 2021 in order to collect further measurement data for evaluation according to the guide "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 65
Instrument 2:	SN 76

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 with the procedure during the laboratory test, the evaluation of the field test is also listed separately for NO and NO_2 in this report.

Measured values were recorded using an external data logger.

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

To carry out the field test, the measuring systems were installed in a measuring station near Cologne. The measuring station is located in the direct vicinity of a busy, six-lane national motorway. The distance from the measuring station to the nearest roadway is approx. 5.0 m

Figure 7: Measuring station used for conducting the field test

The measuring instruments were installed in the station, which was air-conditioned to 20 °C, in a 19" rack and connected to a sampling system. Both systems were installed with a sample gas line of 2.5 m through a T-piece at the same connection of the sampling system. This ensured that both systems performed a representative measurement of the same sample air volume. The sampling head is located on the front side of the measuring station at a total height of approx. 3.00 m.

Figure 8: N500 in the measuring station during the field test

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 to test the performance parameters. 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.

The test gas SN: Test gas bottle (S/N 64616) 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 TRE laboratory.

Zero gas:	**synthetic air**
Test gas NO:	**224.1 ppb in N_2**
Number of test gas cylinder:	16782 (Bottle-SN: 64616)
Manufacturer/manufacturing date:	Linde / 07.04.2020
Stability guarantee / certified:	12 months
Checking of the certificate by / on:	17.06.2020 / UBA Langen Calibration certificate No. 021-2020
Measurement uncertainty as per calibration certificate:	+/- 4.5 nmol/mol
Test gas NO:	**2080 ppb in N_2**
Number of test gas cylinder:	16811
Manufacturer/manufacturing date:	Nippon Gases / 11.03.2020
Stability guarantee / certified:	24 months
Certificate checked by:	Own laboratory
Rel. uncertainty according to certificate:	5%
***Test gas NO_2:**	**4.6 ppm in synth. air**
Number of test gas cylinder:	16806
Manufacturer/manufacturing date:	Nippon Gases / 07.02.2020
Stability guarantee / certified:	12 months
Certificate checked by:	Own laboratory
Rel. uncertainty according to certificate:	5%

Test gas NO_2:	**4.45 ppm in synth. air**
Number of test gas cylinder:	16901
Manufacturer/manufacturing date:	Nippon Gases / 11.01.2021
Stability guarantee / certified:	12 months
Certificate checked by:	Own laboratory
Rel. uncertainty according to certificate:	5%

Test gases marked with "*" were used exclusively for individual test points before the expiry of the stability guarantee.

6. 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 9 shows the measuring system with integrated measured value display.

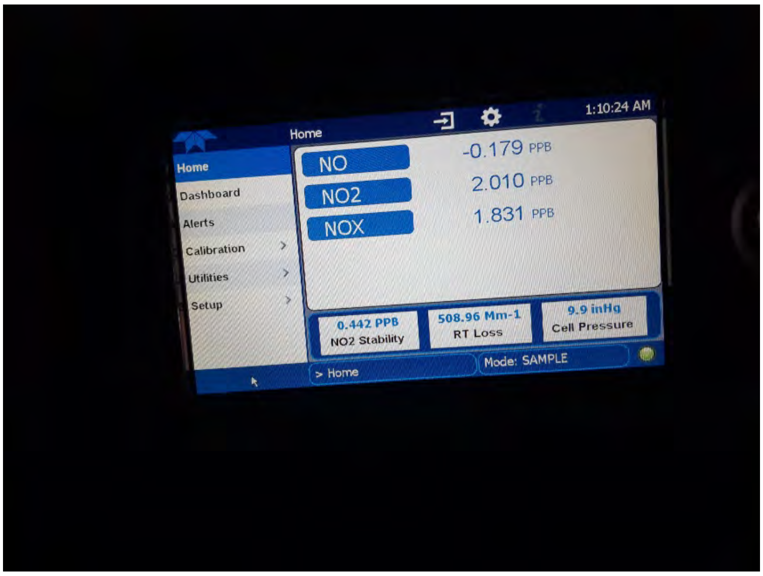


Figure 9: N500 test system with measured value display

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 has a test gas inlet separate from the sample gas inlet at the instrument back.

6.5 Assessment

The measuring system has a test gas inlet separate from the sample gas inlet at the instrument back.

Criterion satisfied? yes

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 large 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 the particle filter at the sample gas inlet. The replacement interval of the particle filter depends on the dust content of the 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

The work on the instruments was carried out during the test based on the work and work procedures described in the manual in chapter 5. 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 system status is continuously monitored and problems are indicated via a number of different warning and status 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 set-up time is of course dependent on the conditions at the installation site as well as the availability of the power supply at the installation site. As the N500 is a compact analyser, the set-up time consists mainly of:

- 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. Information on the set-up time can be found in the manual in chapter 3.2. on page 18.

When switched on from a completely cold state, the system required approx. 60 minutes for the system to complete the warm-up phase and enter measurement mode. The determined warm-up time is in accordance with the information in the manual. In the manual, the warm-up phase is given as approx. 60 minutes (chapter 2.3.4.1, page 28).

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. The set-up time is approx. 0.5 hours and the run-in time approx. one hour, depending on the necessary stabilisation time.

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 power requirement of the measuring system is specified by the manufacturer as 110 W. During start-up (warm-up) a short-term consumption of 220 W was recorded. In normal operation, the consumption is approx. 110 watts, as indicated.

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 at its front with touch panel or via a PC connected to the measuring system directly or via a network.

The instrument provides an internal feature (password protection) to secure it against illicit or unintended adjustment. It is only possible to change parameters or adjust the measuring system after entering the password.

6.4 Evaluation

On entering the correct password, it is possible to change instrument parameters affecting measurement characteristics via the control panel and via an external computer.

6.5 Assessment

The measuring system is secured against unintended and unauthorised adjustment of instrument parameters by way of a password.

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: RS232, RS485, USB, digital and analogue inputs and outputs (optional), TCP/IP network. The measuring system also has the option of outputting analogue signals (optional).

6.4 Evaluation

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

Analogue:	0 – 20, 2 – 20, 4 – 20 mA or 0 – 1/5/10 V, Concentration range selectable
Digital	RS232, USB, digital inputs and outputs, TCP/IP network

6.5 Assessment

The measuring signals are offered in analogue (0 – 20 mA, 4 – 20 mA or 0 – 1V,0 – 5 V, 0 – 10 V) and digital (via TCP/IP, RS 232, USB).

The connection of additional measuring and peripheral devices is possible via corresponding connections on the units.

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/RS485. The measuring system also has the option of outputting 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. Access to unit parameters is password protected.

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

The measuring system has an installed Modbus “Bavaria/Hesse” *(Bayern/Hessen)* transmission protocol as standard. Other data transmission protocols are available in consultation with the manufacturer.

6.4 Evaluation

The measuring system has an installed Modbus “Bavaria/Hesse” *(Bayern/Hessen)* transmission protocol as standard. Other data transmission protocols are available in consultation with the manufacturer. Measured and status signals are transmitted correctly.

6.5 Assessment

The measuring system has an installed Modbus “Bavaria/Hesse” *(Bayern/Hessen)* transmission protocol as standard. Measured and status signals are transmitted correctly. The configuration is listed in the manual in Appendix A.2

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.

The possible measuring range for NO: 1 ppm
The possible measuring range for NO_2: 1 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. Other measuring ranges up to a maximum of 0 – 1 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 component	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 (live 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. An operational status signal is displayed during the warm-up phase.

6.5 Assessment

The measuring system is in fault-free operational readiness when the voltage returns and automatically resumes measuring operation after a warm-up phase.

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 has various interfaces such as RS232, RS485, LAN/WLAN or USB and analogue inputs and outputs. For example, the LAN/WLAN interface can be used to establish a simple 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.

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

The measuring system can be monitored and controlled by the operator at the unit or by the telemetric remote control.

6.4 Evaluation

All operating procedures which do not require on-site practical handling may be performed both by the operator on the instrument itself or telemetrically.

6.5 Assessment

In principle, all necessary work for function control can be monitored and controlled directly on the unit or by telemetric remote control.

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 1.6.0.

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 6 shows the software version displayed by the measuring system.

6.1 7.4 Requirements on performance characteristics for testing 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 the 39th 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 before 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 system, 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 carried out with the particle filters associated with the systems.

As described in point 3.3, the adaptive filters mentioned were active by default throughout the test.

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 span 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 chapter 7.1 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 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 correlation between the measured values and the target values must be representable with the aid of a linear analysis 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.

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 7.1 8.4.8 Sensitivity coefficient to sample gas temperature.

6.4 Evaluation

See chapter 7.1 8.4.8 Sensitivity coefficient to sample gas temperature

6.5 Assessment

See chapter 7.1 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 chapter 7.1 8.4.9 Sensitivity coefficient to surrounding temperature

6.5 Assessment

See chapter 7.1 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 span 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 span 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

Test gases, mixing station

6.3 Testing

The measuring system does not work according to the reference method chemiluminescence but measures NO and NO_2 directly. The execution and evaluation for the determination of the cross-sensitivities according to EN 14211 (2012) and VDI 4202-1 (2018) is adapted to the reference method in the selection of the cross-sensitivity components. Therefore, in addition to the three interferents mentioned in EN 14211, other interference components possible in normal ambient air were checked for their influence. As the measuring system analyses the sample air in the UV range, only other interferents with optical absorption lines in the UV range were considered. The additional interfering components checked were SO_2, H_2S, m-xylene and toluene.

The procedure and evaluation for determining the cross-sensitivities according to EN 14211 (2012) is described in chapter 7.1 8.4.11 Interferents. The contribution to the overall uncertainty from the cross-sensitivity is also determined from the examination carried out strictly according to 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 sums up the positive and negative sums of the deviations. The interferents to be checked according to EN 14211 (H_2O, CO_2 and NH_3) are also listed in this evaluation. The level of the test gas concentrations was selected on the basis of VDI 4201-1 (2018). The concentration level of the interferents was selected on the basis of the guideline VDI 4202-1 (2018). For the component SO_2 the 1-hour limit value was chosen.

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

AMS: N500
Component: NO (certification range = 0 - 962 nmol/mol)

Interferent			AMS 1 Zero point Nominal value nmol/mol	Zero point Reading nmol/mol	Zero point %TG	Zero point Deviation nmol/mol	Span point Nominal value nmol/mol	Span point Reading nmol/mol	Span point %TG	Span point Deviation nmol/mol
SO_2	131	nmol/mol	0.4	0.8	≤ 0.50	0.40	500.4	500.0	≤ 0.50	-0.40
H_2S	200	nmol/mol	0.4	0.4	≤ 0.50	0.00	503.7	504.5	≤ 0.50	0.80
CO_2	500	µmol/mol	0.4	0.8	≤ 0.50	0.40	500.0	501.8	≤ 0.50	1.80
m-Xylol	1	µmol/mol	0.2	1.0	≤ 0.50	0.80	503.7	506.1	≤ 0.50	2.40
Toluol	0.5	µmol/mol	0.6	0.6	≤ 0.50	0.00	504.5	504.7	≤ 0.50	0.20
H_2O	19	mmol/mol	0.0	0.0	≤ 0.50	0.00	506.5	506.9	≤ 0.50	0.40
NH_3	200	nmol/mol	0.6	1.2	≤ 0.50	0.60	503.4	504.6	≤ 0.50	1.20
Sum of positive deviations						**2.20**				**6.80**
Sum of negative deviations						**0.00**				**-0.40**

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

AMS: N500
Component: NO (certification range = 0 - 962 nmol/mol)

Interferent			AMS 2 Zero point Nominal value nmol/mol	Zero point Reading nmol/mol	Zero point %TG	Zero point Deviation nmol/mol	Span point Nominal value nmol/mol	Span point Reading nmol/mol	Span point %TG	Span point Deviation nmol/mol
SO_2	131	nmol/mol	0.6	0.4	≤ 0.50	-0.20	501.4	500.8	≤ 0.50	-0.60
H_2S	200	nmol/mol	0.0	0.0	≤ 0.50	0.00	504.3	506.7	≤ 0.50	2.40
CO_2	500	µmol/mol	0.0	0.4	≤ 0.50	0.40	501.4	502.2	≤ 0.50	0.80
m-Xylol	1	µmol/mol	0.0	1.0	≤ 0.50	1.00	504.5	506.7	≤ 0.50	2.20
Toluol	0.5	µmol/mol	0.0	0.0	≤ 0.50	0.00	506.3	506.5	≤ 0.50	0.20
H_2O	19	mmol/mol	0.0	-0.6	≤ 0.50	-0.60	506.7	508.3	≤ 0.50	1.60
NH_3	200	nmol/mol	0.0	1.2	≤ 0.50	1.20	506.1	507.5	≤ 0.50	1.40
Sum of positive deviations						**2.60**				**8.60**
Sum of negative deviations						**-0.80**				**-0.60**

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

AMS: N500
Component: NO2 (certification range = 0 - 261 nmol/mol)

Interferent			AMS 1 Zero point Nominal value nmol/mol	Zero point Reading nmol/mol	Zero point %TG	Zero point Deviation nmol/mol	Span point Nominal value nmol/mol	Span point Reading nmol/mol	Span point %TG	Span point Deviation nmol/mol
SO_2	131	nmol/mol	-0.2	-0.2	≤ 0.50	0.00	108.1	108.8	0.65	0.70
H_2S	200	nmol/mol	-0.2	-0.2	≤ 0.50	0.00	106.8	108.2	1.31	1.40
CO_2	500	µmol/mol	-0.2	-0.2	≤ 0.50	0.00	105.8	106.5	0.66	0.70
m-Xylol	1	µmol/mol	-0.2	-0.2	≤ 0.50	0.00	107.6	109.6	1.86	2.00
Toluol	0.5	µmol/mol	-0.2	-0.2	≤ 0.50	0.00	108.5	108.3	≤ 0.50	-0.20
H_2O	19	mmol/mol	0.1	0.3	≤ 0.50	0.20	106.2	106.5	≤ 0.50	0.30
NH_3	200	nmol/mol	-0.2	-0.2	≤ 0.50	0.00	107.0	108.1	1.03	1.10
Sum of positive deviations						**0.20**				**6.20**
Sum of negative deviations						**0.00**				**-0.20**

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

AMS: N500
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	-1.0	-1.0	≤ 0.50	0.00	107.9	108.7	0.74	0.80
H_2S	200 nmol/mol	-0.9	-1.0	≤ 0.50	-0.10	108.3	109.5	1.11	1.20
CO_2	500 µmol/mol	-0.4	-0.7	≤ 0.50	-0.30	105.6	106.4	0.76	0.80
m-Xylol	1 µmol/mol	-1.0	-1.0	≤ 0.50	0.00	107.6	109.5	1.77	1.90
Toluol	0.5 µmol/mol	-1.0	-1.0	≤ 0.50	0.00	108.4	108.2	≤ 0.50	-0.20
H_2O	19 mmol/mol	0.3	0.3	≤ 0.50	0.00	106.6	106.8	≤ 0.50	0.20
NH_3	200 nmol/mol	-0.8	-1.0	≤ 0.50	-0.20	106.9	107.9	0.94	1.00
Sum of positive deviations					**0.00**				**5.90**
Sum of negative deviations					**-0.60**				**-0.20**

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. This would be related to the measuring range 0 – 962 nmol/mol = 28.86 nmol/mol allowed deviation for the component NO. For the component NO_2 the permissible deviation for the measuring range 0 – 261 nmol/mol is 7.83 nmol/mol. These values are safely complied with, as shown in Table 4 to Table 7.

The influence of the cross-sensitivity also fulfils the requirement of VDI 4202-1 (2018) for measurement principles that deviate from the EN standards.

Criterion satisfied? yes

6.6 Detailed presentation of test results

The individual values of the cross-sensitivity tests carried out are shown in the following tables.

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

AMS: N500
Component: NO (certification range = 0 – 962 mg/m³)
Measurement date: 23.10.2020 to 26.10.2020

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	0.60	0.60	1.20	0.80
H_2S	200	nmol/mol	0.40	0.60	0.60	0.00	0.40
CO_2	500	µmol/mol	0.40	0.60	0.60	1.20	0.80
m-Xylene	1	µmol/mol	0.20	0.60	1.20	1.20	1.00
Toluene	0.5	µmol/mol	0.60	0.60	0.60	0.60	0.60
H_2O	19	mmol/mol	0.00	0.00	0.00	0.00	0.00
NH_3	200	nmol/mol	0.60	1.20	1.20	1.20	1.20

System 1			Span point				
Interferent			Nominal value nmol/mol	1. nmol/mol	2. nmol/mol	3. nmol/mol	∅ nmol/mol
SO_2	131	nmol/mol	500.44	500.24	500.24	499.64	500.04
H_2S	200	nmol/mol	503.65	503.85	504.45	505.05	504.45
CO_2	500	µmol/mol	500.00	502.00	501.40	502.00	501.80
m-Xylene	1	µmol/mol	503.65	506.25	505.65	506.25	506.05
Toluene	0.5	µmol/mol	504.45	505.05	504.45	504.45	504.65
H_2O	19	mmol/mol	506.47	507.50	508.70	504.40	506.87
NH_3	200	nmol/mol	503.40	505.10	504.40	504.40	504.63

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

AMS: N500
Component: NO (certification range = 0 – 962 mg/m³)
Measurement date: 23.10.2020 to 26.10.2020

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	0.60	0.00	0.00	1.20	0.40
H_2S	200	nmol/mol	0.00	0.00	0.00	0.00	0.00
CO_2	500	µmol/mol	0.00	0.00	0.00	1.20	0.40
m-Xylene	1	µmol/mol	0.00	1.20	0.60	1.20	1.00
Toluene	0.5	µmol/mol	0.00	0.00	0.00	0.00	0.00
H_2O	19	mmol/mol	0.00	-0.60	-0.60	-0.60	-0.60
NH_3	200	nmol/mol	0.00	1.20	1.20	1.20	1.20

System 2			Span point				
Interferent			Nominal value nmol/mol	1. nmol/mol	2. nmol/mol	3. nmol/mol	∅ nmol/mol
SO_2	131	nmol/mol	501.44	500.24	501.44	500.84	500.84
H_2S	200	nmol/mol	504.25	506.85	506.25	506.85	506.65
CO_2	500	µmol/mol	501.40	502.60	502.00	502.00	502.20
m-Xylene	1	µmol/mol	504.45	506.25	506.25	507.46	506.65
Toluene	0.5	µmol/mol	506.25	505.65	506.85	506.85	506.45
H_2O	19	mmol/mol	506.67	508.70	506.90	509.30	508.30
NH_3	200	nmol/mol	506.10	506.90	507.50	508.10	507.50

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

AMS: N500
Component: NO_2 (certification range = 0 - 261 nmol/mol)
Measurement date: 23.10.2020 to 28.10.2020

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	-0.16	-0.16	-0.16	-0.16	-0.16
H_2S	200	nmol/mol	-0.16	-0.16	-0.16	-0.16	-0.16
CO_2	500	µmol/mol	-0.20	-0.20	-0.20	-0.20	-0.20
m-Xylene	1	µmol/mol	-0.16	-0.16	-0.16	-0.16	-0.16
Toluene	0.5	µmol/mol	-0.16	-0.16	-0.16	-0.16	-0.16
H_2O	19	mmol/mol	0.07	0.30	0.30	0.30	0.30
NH_3	200	nmol/mol	-0.20	-0.20	-0.20	-0.20	-0.20

System 1			Span point				
Interferent			Nominal value nmol/mol	1. nmol/mol	2. nmol/mol	3. nmol/mol	∅ nmol/mol
SO_2	131	nmol/mol	108.10	108.80	108.80	108.80	108.80
H_2S	200	nmol/mol	106.82	108.23	108.23	108.23	108.23
CO_2	500	µmol/mol	105.77	106.40	106.50	106.50	106.47
m-Xylene	1	µmol/mol	107.61	109.62	109.62	109.62	109.62
Toluene	0.5	µmol/mol	108.53	108.48	108.48	107.83	108.26
H_2O	19	mmol/mol	106.20	106.40	106.50	106.70	106.53
NH_3	200	nmol/mol	107.03	108.00	108.20	108.20	108.13

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

AMS: N500
Component: NO_2 (certification range = 0 - 261 nmol/mol)
Measurement date: 23.10.2020 to 28.10.2020

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	-1.03	-1.14	-0.98	-0.98	-1.03
H_2S	200	nmol/mol	-0.87	-0.98	-0.98	-0.98	-0.98
CO_2	500	µmol/mol	-0.44	-0.70	-0.70	-0.70	-0.70
m-Xylene	1	µmol/mol	-0.98	-0.98	-0.98	-0.98	-0.98
Toluene	0.5	µmol/mol	-0.98	-0.98	-0.98	-0.98	-0.98
H_2O	19	mmol/mol	0.33	0.30	0.30	0.30	0.30
NH_3	200	nmol/mol	-0.82	-1.00	-1.00	-1.00	-1.00

System 2			Span point				
Interferent			Nominal value nmol/mol	1. nmol/mol	2. nmol/mol	3. nmol/mol	∅ nmol/mol
SO_2	131	nmol/mol	107.94	108.64	108.80	108.80	108.75
H_2S	200	nmol/mol	108.26	110.11	110.11	108.32	109.51
CO_2	500	µmol/mol	105.60	106.20	106.40	106.50	106.37
m-Xylene	1	µmol/mol	107.61	109.46	109.46	109.46	109.46
Toluene	0.5	µmol/mol	108.43	108.32	108.48	107.66	108.15
H_2O	19	mmol/mol	106.57	106.70	106.70	107.00	106.80
NH_3	200	nmol/mol	106.90	107.80	107.80	108.00	107.87

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 $c_{t,NO2}$ 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 span (t_c) of the constant NO concentrations shall be at least equal to the time span necessary to obtain four independent display values (corresponding to at least 16 response times) The time interval (t_v) of the changed NO concentration shall be at least equal to the time interval (t_{NO}) required to obtain four independent display values. The NO concentration must be 45 s followed by the time period (t_{zero}) of 45 s for 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 for NO (X_{av}) is:

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

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} is the average value of at least four independent measurements during the period of variable concentration

The following applies differently for NOx measuring instruments

The averaging influence shall be determined for the measurement components NO_2 and NO. The averaging influence for NO is calculated according to EN 14211. The determination of the averaging effect for NO_2 is calculated according to the following formula:

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

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}	is the average of the at least four independent measurements during the variable concentration period;

The averaging test was carried out according to the specifications of EN 14211 and 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 $c_{t,NO2}$ 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%	3.1	✓	-2.9	✓

This results in the following averaging influences for NO:

System 1: 3.1 %

System 2: -2.9 %

Evaluation for the component NO_2 during the test with NO as described above.

Table 13: Results of the averaging test for NO_2

	requirement	device 1		device 2	
averaging effect E_{av} [%]	≤ 7%	1.5	✓	1.7	✓

This results in the following averaging influences for NO_2:

System 1: 1.5 %

System 2: 1.7 %

6.5 Assessment

The performance criterion of VDI 4202-1 and EN 14211 is fully complied with.

Criterion satisfied? yes

6.6 Detailed presentation of test results

In Table 14 and in Table 15 the individual results of the investigations into the averaging influence are shown.

Table 14: Individual values of the averaging influence study for NO

		device 1	device 2
	time	[nmol/mol]	[nmol/mol]
average constant concentration $C_{av,c}$	11:34:00 till 11:53:00	602.0	615.5
average variable concentration $C_{av,c}$	11:54:00 till 12:13:00	298.9	311.3

		device 1	device 2
	time	[nmol/mol]	[nmol/mol]
average constant concentration $C_{av,c}$	12:24:00 till 12:43:00	605.8	617.6
average variable concentration $C_{av,c}$	12:44:00 till 13:03:00	293.2	314.5

		device 1	device 2
	time	[nmol/mol]	[nmol/mol]
average constant concentration $C_{av,c}$	13:15:00 till 13:34:00	607.1	617.8
average variable concentration $C_{av,c}$	13:35:00 till 13:54:00	287.0	326.0

Table 15: Individual values of the averaging influence study for NO_2

		device 1	device 2
	time	[nmol/mol]	[nmol/mol]
average constant concentration $C_{av,c}$	11:34:00 till 11:53:00	218.5	218.5
average variable concentration $C_{av,c}$	11:54:00 till 12:13:00	215.5	215.8

		device 1	device 2
	time	[nmol/mol]	[nmol/mol]
average constant concentration $C_{av,c}$	12:24:00 till 12:43:00	218.8	220.5
average variable concentration $C_{av,c}$	12:44:00 till 13:03:00	215.6	216.1

		device 1	device 2
	time	[nmol/mol]	[nmol/mol]
average constant concentration $C_{av,c}$	13:15:00 till 13:34:00	219.1	221.8
average variable concentration $C_{av,c}$	13:35:00 till 13:54:00	215.6	217.3

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

Determination and evaluation of the difference between sample and calibration port corresponds exactly to determining the difference sample/calibration port in accordance with standard EN 14211 (2012). The reader is therefore referred to chapter 7.1 8.4.13 Difference sample/calibration port.

6.4 Evaluation

See chapter 7.1 8.4.13 Difference sample/calibration port

6.5 Assessment

See chapter 7.1 8.4.13 Difference sample/calibration port

Criterion satisfied? yes

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 N500 measuring system does not work according to the EU standard reference method of chemiluminescence. Therefore, the measuring system does not have a standard NO-NO_2 converter. The N500 measuring system analyses NO_2 directly in the UV range. NO is determined by oxidising the sample air with ozone in alternating cycles (gas phase titration). The difference between the two measurements is displayed as the NO value. Even if there is no converter in the measuring system to be tested, the test was carried out as indicated above to show that the NO and NO_2 measurement results 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 39th 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 described 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 39th 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. Details on the location of the measuring station are given in chapter 4.3.

6.5 Assessment

The field test location was selected in compliance with the 39th BImSchV. Details on the location of the measuring station are given in chapter 4.3.

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). The reader is therefore referred to the 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 NOx 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 NOx 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 NOx channel. Then, NO is brought to react with O_3 to produce NO_2. This mixture containing a constant NOx 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 NOx 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 NOx 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 NOx channel at the resulting NOx 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 N500 measuring system does not work according to the EU standard reference method of chemiluminescence. Therefore, the measuring system does not have a standard NO-NO_2 converter. The N500 measuring system analyses NO_2 directly in the UV range. NO is determined by oxidising the sample air with ozone in alternating cycles. The difference between the two measurements is displayed as the NO value. Even if there is no converter in the measuring system to be tested, the test was carried out as indicated above to show that the NO and NO_2 measurement results 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 testing, the following converter efficiencies were determined for the two N500 measuring systems. The lowest value of the two NO_2 concentration is reported below.

	requirement	device 1		device 2	
converter efficiency E_c [%]	≥ 95%	99.6	✓	99.5	✓

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]
	11:14:00	start					
O_3=0, NO=50%	11:33:00	0.0	0.0	484.0	490.1	483.9	492.8
	11:34:00	0.0	0.0	491.3	491.5	489.9	491.6
	11:35:00	0.0	0.0	487.6	489.7	488.7	491.6
	11:36:00	0.0	0.0	486.4	489.7	486.3	491.6
average		0.0	0.0	487.3	490.2	487.2	491.9
NO_2= 50%	11:58:00	130.0	133.5	353.5	489.7	357.1	492.2
	11:59:00	130.0	133.2	352.9	489.7	356.5	491.0
130.75	12:00:00	130.0	132.1	353.5	489.7	356.5	491.0
	12:01:00	130.0	134.5	352.9	489.7	356.5	491.0
average		130.0	133.3	353.2	489.7	356.7	491.3
O_3=0, NO=50%	13:01:00	0.0	0.0	484.7	491.7	489.8	492.5
	13:02:00	0.0	0.0	492.0	491.1	489.2	494.3
	13:03:00	0.0	0.0	488.4	491.1	488.0	493.7
	13:04:00	0.0	0.0	487.1	494.1	488.0	490.7
average		0.0	0.0	488.1	492.0	488.7	492.8
NO_2= 95%	13:25:00	248.0	252.6	239.2	491.7	237.7	494.9
	13:26:00	248.0	250.2	241.6	491.7	237.7	492.5
248.43	13:27:00	248.0	251.4	239.8	491.1	235.9	494.3
	13:28:00	248.0	253.2	237.9	491.1	235.3	493.7
average		248.0	251.8	239.6	491.4	236.7	493.8
O_3=0, NO=50%	13:38:00	0.0	0.0	487.1	491.7	483.2	494.9

6.1 7.6 Type approval and calculation of the measurement uncertainty

The type approval of the measuring system requires the following:

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

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.

7. 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 must be mounted directly at the inlet of the meter and both zero and span gas must be supplied with the same excess, which is discharged by means of a T-piece. The gas flows of zero and span gas must be selected in such a way that the dead time in the valve and in the T-piece is negligible compared to the dead time of the meter. 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 for the dead time (rise) as shown in Figure 10. 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 10 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.

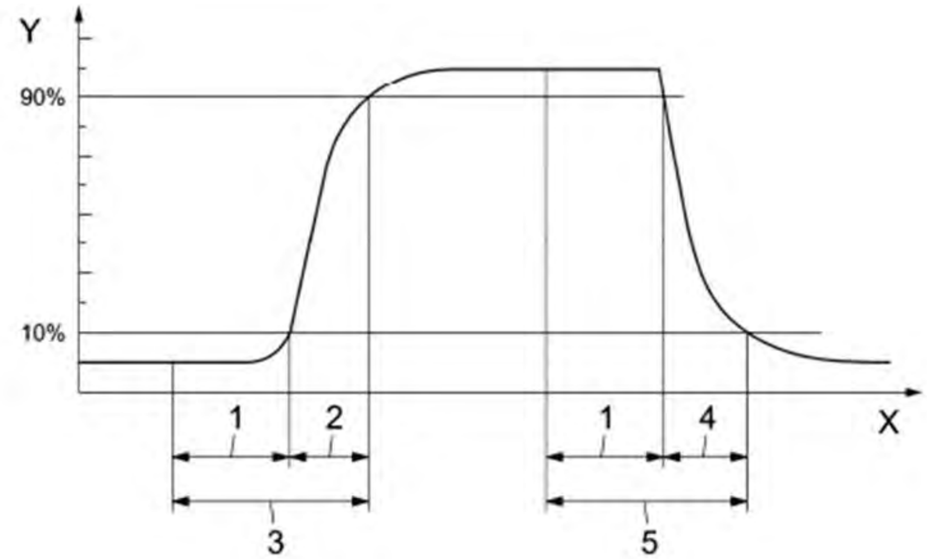
The test shall then be repeated with NO_2 at levels from less than 20 % to about 80 % of the maximum of the certification range of NO_2 and vice versa.

The difference in response times shall be calculated according to:

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

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 10: 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 N500 measuring systems for NO

	requirement	device 1		device 2	
average rise t_r [s]	≤ 180 s	24	✓	25	✓
average fall t_f [s]	≤ 180 s	22	✓	23	✓
difference t_d [s]	≤ 10 s	2.0	✓	2.0	✓

For system 1, the average t_r for NO was 24 sec, the average t_f was 22 sec and the average t_d was 2 sec.

For system 2, the average t_r for NO was 25 sec, the average t_f was 23 sec and the average t_d was 2 sec.

Table 18: Response times of the two N500 measuring systems for NO_2

	requirement	device 1		device 2	
average rise t_r [s]	≤ 180 s	24	✓	25	✓
average fall t_f [s]	≤ 180 s	22	✓	22	✓
difference t_d [s]	≤ 10 s	2.0	✓	3.0	✓

For unit 1, the average t_r for NO_2 was 24 sec, the average t_f was 22 sec and the average t_d was 2 sec.

For unit 2, the average t_r for NO_2 was 25 sec, the average t_f was 22 sec and the average t_d was 3 sec.

7.5 Assessment

The values determined remained considerably below the maximum permissible response time of 180 s at all times. The maximum determined response time for unit 1 was 24 sec for NO and 24 sec for NO_2. For unit 2 it was 25 sec for NO and 25 sec 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	15:14:00	15:14:24	15:15:00	15:20:00	15:20:21	15:22:00
	delta t		00:00:24			00:00:21	
	delta t [s]		24			21	
cycle 2	t = 0	15:27:00	15:27:24	15:28:00	15:33:00	15:33:23	15:34:00
	delta t		00:00:24			00:00:23	
	delta t [s]		24			23	
cycle 3	t = 0	15:39:00	15:39:26	15:40:00	15:45:00	15:45:22	15:46:00
	delta t		00:00:26			00:00:22	
	delta t [s]		26			22	
cycle 4	t = 0	15:51:00	15:51:22	15:52:00	15:57:00	15:57:22	15:58:00
	delta t		00:00:22			00:00:22	
	delta t [s]		22			22	

		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	15:14:00	15:14:25	15:15:00	15:20:00	15:20:22	15:22:00
	delta t		00:00:25			00:00:22	
	delta t [s]		25			22	
cycle 2	t = 0	15:27:00	15:27:27	15:28:00	15:33:00	15:33:26	15:34:00
	delta t		00:00:27			00:00:26	
	delta t [s]		27			26	
cycle 3	t = 0	15:39:00	15:39:24	15:40:00	15:45:00	15:45:21	15:46:00
	delta t		00:00:24			00:00:21	
	delta t [s]		24			21	
cycle 4	t = 0	15:51:00	15:51:24	15:52:00	15:57:00	15:57:23	15:58:00
	delta t		00:00:24			00:00:23	
	delta t [s]		24			23	

Table 20: Individual results of the response time for NO_2

	80%	device 1 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	07:46:00	07:46:24	07:47:00	07:52:00	07:52:22	07:53:00
	delta t		00:00:24			00:00:22	
	delta t [s]		24			22	
cycle 2	t = 0	08:00:00	08:00:24	08:01:00	08:06:00	08:06:23	08:07:00
	delta t		00:00:24			00:00:23	
	delta t [s]		24			23	
cycle 3	t = 0	08:11:00	08:11:24	08:12:00	08:17:00	08:17:23	08:18:00
	delta t		00:00:24			00:00:23	
	delta t [s]		24			23	
cycle 4	t = 0	08:23:00	08:23:24	08:24:00	08:29:00	08:29:20	08:30:00
	delta t		00:00:24			00:00:20	
	delta t [s]		24			20	

	80%	device 2 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	07:46:00	07:46:25	07:47:00	07:52:00	07:52:23	07:53:00
	delta t		00:00:25			00:00:23	
	delta t [s]		25			23	
cycle 2	t = 0	08:00:00	08:00:24	08:01:00	08:06:00	08:06:22	08:07:00
	delta t		00:00:24			00:00:22	
	delta t [s]		24			22	
cycle 3	t = 0	08:11:00	08:11:25	08:12:00	08:17:00	08:17:22	08:18:00
	delta t		00:00:25			00:00:22	
	delta t [s]		25			22	
cycle 4	t = 0	08:23:00	08:23:26	08:24:00	08:29:00	08:29:21	08:30:00
	delta t		00:00:26			00:00:21	
	delta t [s]		26			21	

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 span 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.

The test was also carried out for the NO_2 component at a concentration level of 70 % to 80 % of the certification range for NO_2.

7.4 Evaluation

In Table 21 and in Table 22 the measured values of the short-term drift are presented.

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

	requirements	device 1		device 2	
averange at zero at the beginning [nmol/mol]	-	-0.54		-0.30	
averange at zero at the end (12h) [nmol/mol]	-	-0.48		-0.57	
averange at span at the beginning [nmol/mol]	-	708.06		714.83	
averange at span at the end (12h) [nmol/mol]	-	710.48		715.66	
12-hour drift at zero $D_{s,z}$ [nmol/mol]	≤ 2.0	0.06	✓	-0.27	✓
12-hour drift at span $D_{s,s}$ [nmol/mol]	≤ 6.0	2.36	✓	1.11	✓

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

	requirements	device 1		device 2	
averange at zero at the beginning [nmol/mol]	-	-0.13		-0.27	
averange at zero at the end (12h) [nmol/mol]	-	-0.16		-0.53	
averange at span at the beginning [nmol/mol]	-	207.91		208.74	
averange at span at the end (12h) [nmol/mol]	-	210.64		211.20	
12-hour drift at zero $D_{s,z}$ [nmol/mol]	≤ 2.0	-0.03	✓	-0.26	✓
12-hour drift at span $D_{s,s}$ [nmol/mol]	≤ 6.0	2.76	✓	2.72	✓

7.5 Assessment

For NO, the value for the short-term drift at zero point was 0.06 nmol/mol for instrument 1; for instrument 2, it was -0.27 nmol/mol.

For NO, the value for the short-term drift at span point was 2.36 nmol/mol for instrument 1; for instrument 2, it was 1.11 nmol/mol.

For NO_2, the value for the short-term drift at zero point was -0.03 nmol/mol for instrument 1; for instrument 2, it was -0.26 nmol/mol.

For NO_2, the value for the short-term drift at span point was 2.76 nmol/mol for instrument 1; for instrument 2, it was 2.72 nmol/mol.

Criterion satisfied? yes

7.6 Detailed presentation of test results

The individual values of the test are shown in Table 23 to Table 26.

Table 23: Results of the short-term drift 1st test gas for NO

at beginning (19.10.2020)		
zero level		
	device 1	device 2
time	[nmol/mol]	[nmol/mol]
16:36:00	0.0	0.0
16:37:00	-0.6	0.0
16:38:00	-0.6	-0.6
16:39:00	-0.6	-0.6
16:40:00	-0.6	0.0
16:41:00	-0.6	-0.6
16:42:00	-0.6	-0.6
16:43:00	-0.6	-0.6
16:44:00	-0.6	-0.6
16:45:00	-0.6	0.0
16:46:00	-0.6	0.0
16:47:00	-0.6	0.0
16:48:00	-0.6	0.0
16:49:00	0.0	-0.6
16:50:00	-0.6	0.0
16:51:00	-0.6	0.0
16:52:00	-0.6	0.0
16:53:00	-0.6	-0.6
16:54:00	-0.6	-0.6
16:55:00	-0.6	-0.6
average	**-0.5**	**-0.3**

at beginning (19.10.2020)		
span level		
	device 1	device 2
time	[nmol/mol]	[nmol/mol]
17:11:00	707.0	713.7
17:12:00	706.4	713.7
17:13:00	705.7	713.1
17:14:00	710.3	719.1
17:15:00	708.8	715.5
17:16:00	707.0	713.7
17:17:00	706.9	713.7
17:18:00	713.3	717.9
17:19:00	707.6	714.3
17:20:00	707.0	713.7
17:21:00	705.7	713.1
17:22:00	710.3	716.7
17:23:00	707.0	715.5
17:24:00	708.2	713.7
17:25:00	704.6	710.1
17:26:00	715.0	719.1
17:27:00	708.8	714.9
17:28:00	706.4	714.9
17:29:00	706.4	713.1
17:30:00	708.8	717.3
average	**708.1**	**714.8**

Table 24: Results of the short-term drift 2nd test gas for NO

after 12h (20.10.2020)		
zero level		
	device 1	device 2
time	[nmol/mol]	[nmol/mol]
04:36:00	0.0	-0.6
04:37:00	0.0	-0.6
04:38:00	-0.6	-0.6
04:39:00	-0.6	-0.6
04:40:00	-0.6	0.0
04:41:00	-0.6	-0.6
04:42:00	-0.6	-0.6
04:43:00	-0.6	-0.6
04:44:00	-0.6	-0.6
04:45:00	-0.6	-0.6
04:46:00	0.0	-0.6
04:47:00	-0.6	-0.6
04:48:00	-0.6	-0.6
04:49:00	0.0	-0.6
04:50:00	-0.6	-0.6
04:51:00	-0.6	-0.6
04:52:00	-0.6	-0.6
04:53:00	-0.6	-0.6
04:54:00	-0.6	-0.6
04:55:00	-0.6	-0.6
average	**-0.5**	**-0.6**

after 12h (20.10.2020)		
span level		
	device 1	device 2
time	[nmol/mol]	[nmol/mol]
05:11:00	711.1	715.3
05:12:00	710.8	717.9
05:13:00	711.8	716.5
05:14:00	711.2	715.3
05:15:00	712.3	711.7
05:16:00	712.5	716.1
05:17:00	709.3	716.5
05:18:00	711.2	715.3
05:19:00	707.6	714.1
05:20:00	708.9	717.8
05:21:00	711.3	716.6
05:22:00	710.6	715.9
05:23:00	710.6	716.5
05:24:00	709.3	715.3
05:25:00	710.4	714.9
05:26:00	710.6	716.5
05:27:00	711.2	715.9
05:28:00	707.5	713.5
05:29:00	710.2	719.1
05:30:00	711.2	712.3
average	**710.5**	**715.7**

Table 25: Results of the short-term drift 1st test gas for NO_2

at beginning (15.10.2020)		
zero level		
	device 1	device 2
time	[nmol/mol]	[nmol/mol]
15:41:00	0.0	-0.2
15:42:00	0.0	-0.2
15:43:00	0.0	-0.2
15:44:00	0.0	-0.2
15:45:00	-0.2	-0.2
15:46:00	-0.2	-0.3
15:47:00	-0.2	-0.2
15:48:00	-0.2	-0.2
15:49:00	-0.2	-0.3
15:50:00	-0.2	-0.3
15:51:00	-0.2	-0.3
15:52:00	-0.2	-0.3
15:53:00	-0.2	-0.3
15:54:00	-0.2	-0.3
15:55:00	-0.2	-0.3
15:56:00	-0.2	-0.3
15:57:00	-0.2	-0.3
15:58:00	-0.2	-0.3
15:59:00	-0.2	-0.3
16:00:00	-0.2	-0.3
average	**-0.1**	**-0.3**

at beginning (15.10.2020)		
span level		
	device 1	device 2
time	[nmol/mol]	[nmol/mol]
16:16:00	206.8	207.8
16:17:00	207.0	207.8
16:18:00	207.3	208.1
16:19:00	207.3	208.1
16:20:00	207.5	208.3
16:21:00	207.5	208.5
16:22:00	207.7	208.6
16:23:00	207.7	208.6
16:24:00	207.8	208.6
16:25:00	208.0	208.8
16:26:00	208.0	208.8
16:27:00	208.0	208.8
16:28:00	208.1	209.0
16:29:00	208.3	209.0
16:30:00	208.3	209.1
16:31:00	208.5	209.1
16:32:00	208.5	209.3
16:33:00	208.5	209.3
16:34:00	208.6	209.5
16:35:00	208.8	209.6
average	**207.9**	**208.7**

Table 26: Results of the short-term drift 2nd test gas for NO_2

after 12h (16.10.2020)		
zero level		
	device 1	device 2
time	[nmol/mol]	[nmol/mol]
03:41:00	-0.2	-0.5
03:42:00	-0.2	-0.5
03:43:00	-0.2	-0.5
03:44:00	-0.2	-0.5
03:45:00	-0.2	-0.5
03:46:00	-0.2	-0.5
03:47:00	-0.2	-0.5
03:48:00	-0.2	-0.5
03:49:00	-0.2	-0.5
03:50:00	-0.2	-0.5
03:51:00	-0.2	-0.5
03:52:00	-0.2	-0.7
03:53:00	-0.2	-0.5
03:54:00	-0.2	-0.5
03:55:00	-0.2	-0.7
03:56:00	-0.2	-0.7
03:57:00	-0.2	-0.7
03:58:00	-0.2	-0.5
03:59:00	-0.2	-0.5
04:00:00	-0.2	-0.7
average	**-0.2**	**-0.5**

after 12h (16.10.2020)		
span level		
	device 1	device 2
time	[nmol/mol]	[nmol/mol]
04:16:00	210.1	210.6
04:17:00	210.3	210.8
04:18:00	210.3	210.8
04:19:00	210.4	210.9
04:20:00	210.4	210.9
04:21:00	210.4	211.1
04:22:00	210.4	211.1
04:23:00	210.6	211.1
04:24:00	210.6	211.1
04:25:00	210.6	211.1
04:26:00	210.6	211.2
04:27:00	210.8	211.2
04:28:00	210.8	211.4
04:29:00	210.8	211.4
04:30:00	210.9	211.6
04:31:00	210.9	211.6
04:32:00	210.9	211.6
04:33:00	210.9	211.4
04:34:00	211.1	211.6
04:35:00	211.1	211.6
average	**210.6**	**211.2**

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 3.0 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:

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

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.

The test was also carried out for the component NO_2 at the zero point and at a span concentration at the level of the 1-h limit value of NO_2 (104 nmol/mol).

7.4 Evaluation

In Table 27 and in Table 28 the results of the repeatability standard deviation test are presented.

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

	requirement	device 1		device 2	
repeatability standard deviation $s_{r,z}$ at zero [nmol/mol]	≤ 1.0	0.13	✓	0.13	✓
repeatability standard deviation $s_{r,ct}$ at c_t [nmol/mol]	≤ 3.0	1.63	✓	1.34	✓
detection limit [nmol/mol]		0.45		0.45	

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

	requirement	device 1		device 2	
repeatability standard deviation $s_{r,z}$ at zero [nmol/mol]	≤ 1.0	0.00	✓	0.11	✓
repeatability standard deviation $s_{r,ct}$ at c_t [nmol/mol]	≤ 3.0	0.08	✓	0.08	✓
detection limit [nmol/mol]		0.00		0.36	

7.5 Assessment

For NO, the value for the repeatability standard deviation at zero point was 0.13 nmol/mol for instrument 1; for instrument 2 it was 0.13 nmol/mol. Repeatability standard deviation at span point was 1.63 nmol/mol for instrument 1 and 1.34 nmol/mol for instrument 2.

For NO_2, the value for the repeatability standard deviation at zero point was 0.00 nmol/mol for instrument 1 and 0.11 nmol/mol for instrument 2. Repeatability standard deviation at span point was 0.08 nmol/mol for instrument 1 and 0.08 nmol/mol for instrument 2.

Criterion satisfied? yes

7.6 Detailed presentation of test results

In Table 29 and in Table 30 the results of the individual measurements are presented.

Table 29: Repeatability standard deviation for NO

zero level		
	device 1	device 2
time	[nmol/mol]	[nmol/mol]
17:17:00	0.0	0.0
17:18:00	-0.6	-0.6
17:19:00	-0.6	-0.6
17:20:00	-0.6	-0.6
17:21:00	-0.6	-0.6
17:22:00	-0.6	-0.6
17:23:00	-0.6	-0.6
17:24:00	-0.6	-0.6
17:25:00	-0.6	-0.6
17:26:00	-0.6	-0.6
17:27:00	-0.6	-0.6
17:28:00	-0.6	-0.6
17:29:00	-0.6	-0.6
17:30:00	-0.6	-0.6
17:31:00	-0.6	-0.6
17:32:00	-0.6	-0.6
17:33:00	-0.6	-0.6
17:34:00	-0.6	-0.6
17:35:00	-0.6	-0.6
17:36:00	-0.6	-0.6
average	-0.6	-0.6

c_t level		
	device 1	device 2
time	[nmol/mol]	[nmol/mol]
17:42:00	515.9	521.3
17:43:00	513.5	523.7
17:44:00	513.5	523.1
17:45:00	512.9	524.3
17:46:00	512.9	523.1
17:47:00	512.9	523.7
17:48:00	514.1	522.5
17:49:00	512.3	525.5
17:50:00	517.7	523.7
17:51:00	513.5	523.1
17:52:00	511.7	522.5
17:53:00	514.1	519.5
17:54:00	515.3	522.5
17:55:00	513.5	524.3
17:56:00	513.5	523.7
17:57:00	515.3	524.3
17:58:00	514.7	523.7
17:59:00	512.9	521.3
18:00:00	517.7	522.5
18:01:00	515.3	524.3
average	514.1	523.1

Table 30: Repeatability standard deviation for NO_2

zero level		
	device 1	device 2
time	[nmol/mol]	[nmol/mol]
10:02:00	-0.2	-1.0
10:03:00	-0.2	-1.0
10:04:00	-0.2	-1.0
10:05:00	-0.2	-1.0
10:06:00	-0.2	-1.1
10:07:00	-0.2	-1.1
10:08:00	-0.2	-1.1
10:09:00	-0.2	-1.1
10:10:00	-0.2	-1.1
10:11:00	-0.2	-1.1
10:12:00	-0.2	-1.1
10:13:00	-0.2	-1.1
10:14:00	-0.2	-1.1
10:15:00	-0.2	-1.1
10:16:00	-0.2	-1.1
10:17:00	-0.2	-1.3
10:18:00	-0.2	-1.3
10:19:00	-0.2	-1.3
10:20:00	-0.2	-1.3
10:21:00	-0.2	-1.3
average	-0.2	-1.2

c_t level		
	device 1	device 2
time	[nmol/mol]	[nmol/mol]
10:27:00	104.1	104.1
10:28:00	104.1	104.1
10:29:00	104.1	104.1
10:30:00	104.1	104.1
10:31:00	104.1	104.1
10:32:00	104.1	104.1
10:33:00	104.1	104.1
10:34:00	103.9	103.9
10:35:00	103.9	103.9
10:36:00	103.9	103.9
10:37:00	103.9	103.9
10:38:00	103.9	103.9
10:39:00	103.9	103.9
10:40:00	103.9	103.9
10:41:00	103.9	103.9
10:42:00	103.9	103.9
10:43:00	103.9	103.9
10:44:00	103.9	103.9
10:45:00	103.9	103.9
10:46:00	103.9	103.9
average	104.0	104.0

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 was carried out for the component NO according to the previously mentioned test specifications of EN 14211.

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

7.4 Evaluation

The following linear regressions were established:

In Figure 11 to Figure 14 the results of the group average tests are shown in summary form for NO and NO_2.

Table 31: Deviation from the analytical function for NO

	requirements	device 1		device 2	
largest value of the relative residuals r_{max} [%]	≤ 4.0	1.72	✓	2.24	✓
residual at zero r_z [nmol/mol]	≤ 5.0	-0.60	✓	-0.60	✓

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	0.85	✓	0.72	✓
residual at zero r_z [nmol/mol]	≤ 5.0	-0.16	✓	-0.49	✓

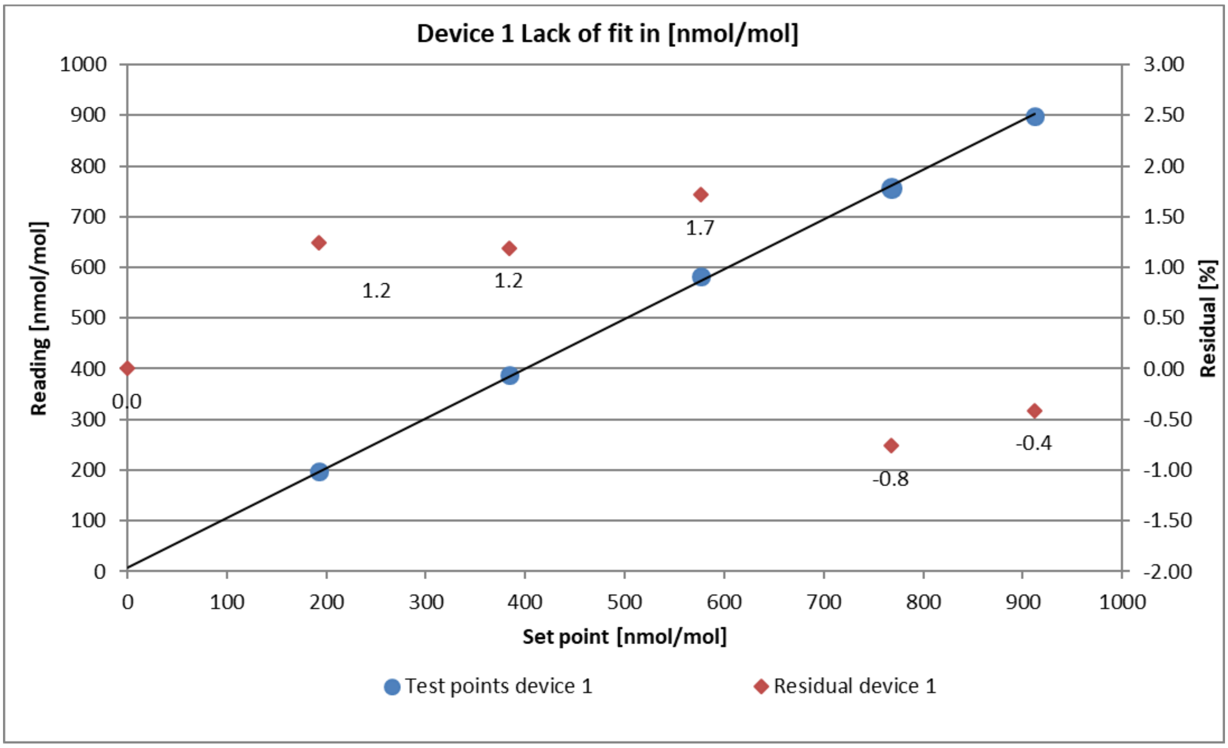


Figure 11: Analysis function from the group average values for system 1 for NO

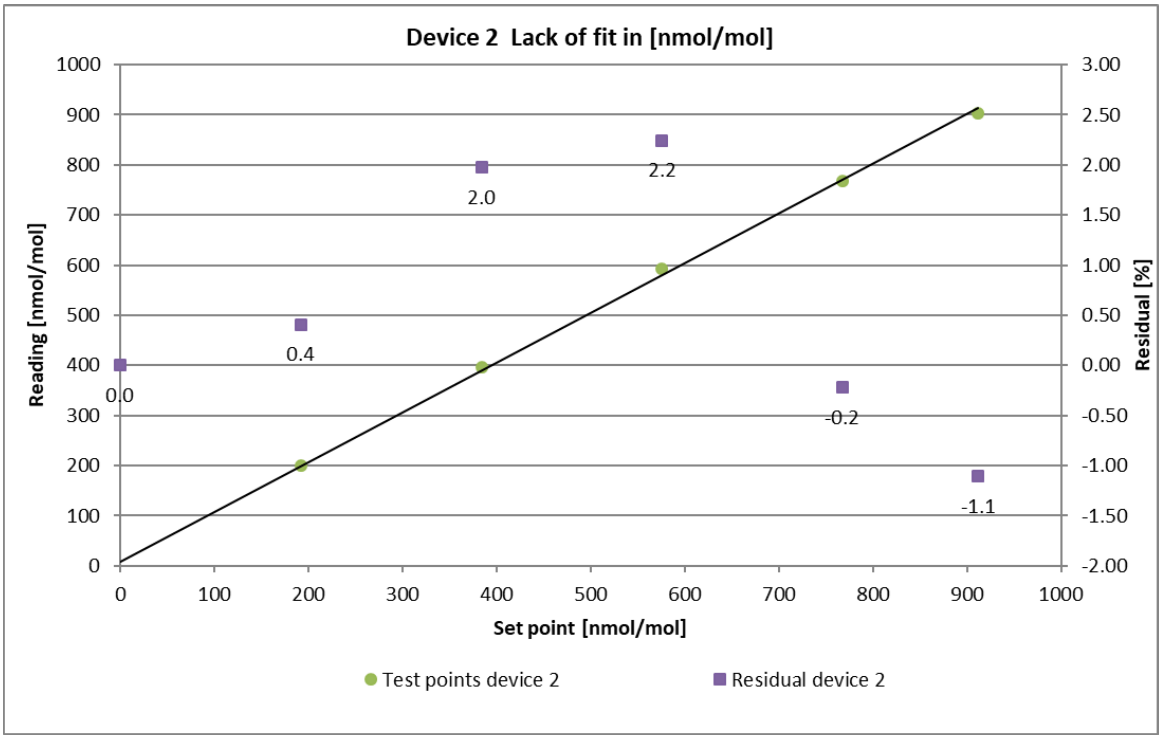


Figure 12: Analysis function from the group average values for system 2 for NO

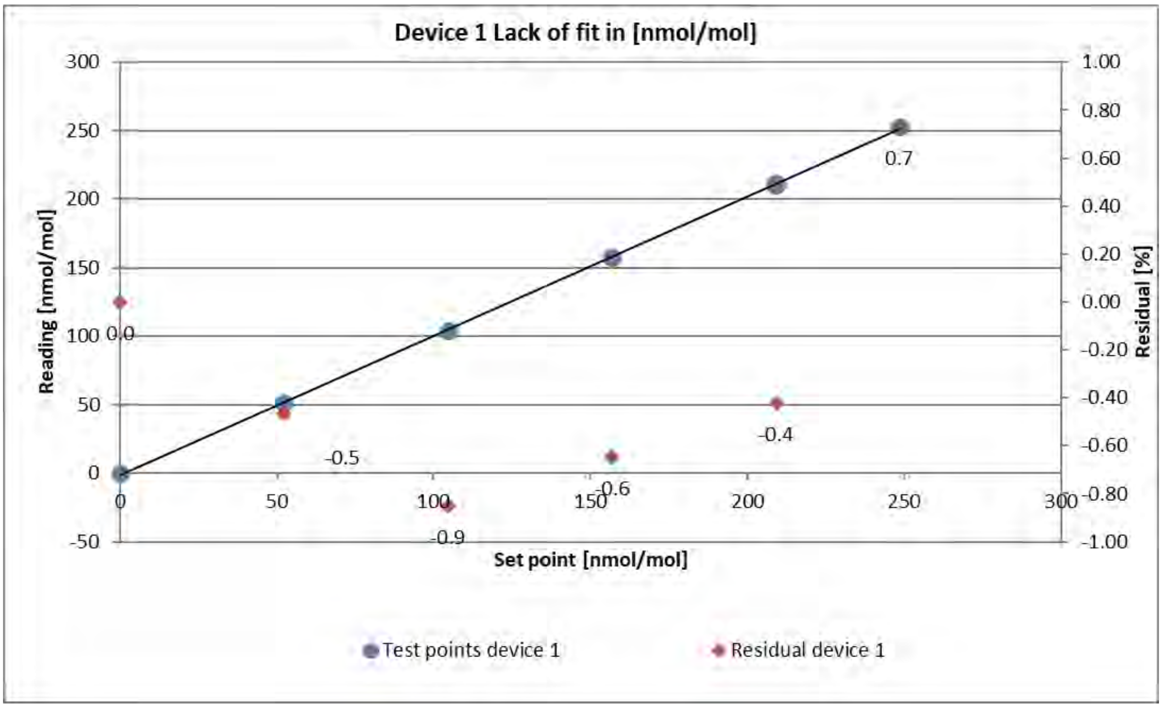


Figure 13: Analysis function from the group average values for system 1 for NO_2

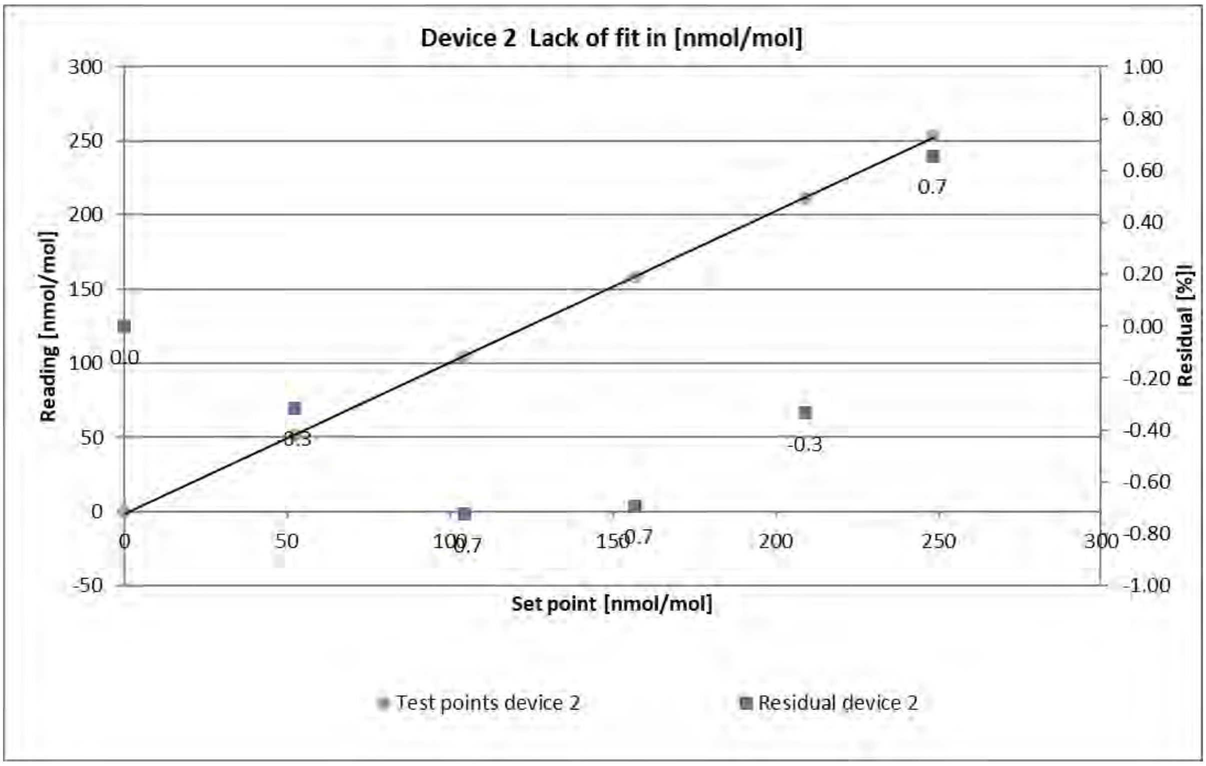


Figure 14: Analysis function from the group average values for system 2 for NO_2

7.5 Assessment

Component NO

The deviation from the linear regression line for instrument 1 is -0.60 nmol/mol at zero point and no more than 1.72% of the rated value for concentrations above zero. The deviation from the linear regression line for instrument 2 is -0.60 nmol/mol at zero point and no more than 2.24% of the rated value for concentrations above zero.

Component NO_2

The deviation from the linear regression line for instrument 1 is -0.16 nmol/mol at zero point and no more than 0.85% of the rated value for concentrations above zero. The deviation from the linear regression line for instrument 2 is -0.49 nmol/mol at zero point and no more than 0.72% of the rated 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

The individual values of the test can be found in Table 33 and in Table 34.

Table 33: 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
08:00:00	80	756.37	768.00	772.01	768.00
08:01:00	80	755.17	768.00	768.40	768.00
08:02:00	80	753.37	768.00	766.59	768.00
08:03:00	80	756.37	768.00	772.01	768.00
08:04:00	80	753.37	768.00	765.39	768.00
average		754.93		768.88	
$r_{c,rel}$		-0.76		-0.22	
08:08:00	40	386.00	384.00	397.43	384.00
08:09:00	40	387.21	384.00	397.43	384.00
08:10:00	40	389.01	384.00	396.83	384.00
08:11:00	40	389.61	384.00	397.43	384.00
08:12:00	40	389.61	384.00	397.43	384.00
average		388.29		397.31	
$r_{c,rel}$		1.19		1.97	
08:16:00	0	-0.60	0.00	-0.60	0.00
08:17:00	0	-0.60	0.00	-0.60	0.00
08:18:00	0	-0.60	0.00	-0.60	0.00
08:19:00	0	-0.60	0.00	-0.60	0.00
08:20:00	0	-0.60	0.00	-0.60	0.00
average		-0.60		-0.60	
r_z					
08:24:00	60	583.21	576.00	596.44	576.00
08:25:00	60	582.01	576.00	595.24	576.00
08:26:00	60	579.00	576.00	582.61	576.00
08:27:00	60	585.02	576.00	595.84	576.00
08:28:00	60	581.41	576.00	595.24	576.00
average		582.13		593.07	
$r_{c,rel}$		1.72		2.24	
08:32:00	20	198.41	192.00	200.82	192.00
08:33:00	20	197.81	192.00	200.22	192.00
08:34:00	20	197.21	192.00	200.22	192.00
08:35:00	20	197.21	192.00	199.62	192.00
08:36:00	20	197.21	192.00	199.62	192.00
average		197.57		200.10	
$r_{c,rel}$		1.24		0.41	
08:40:00	95	899.47	912.00	897.07	912.00
08:41:00	95	901.27	912.00	905.48	912.00
08:42:00	95	899.47	912.00	904.28	912.00
08:43:00	95	895.26	912.00	906.69	912.00
08:44:00	95	896.46	912.00	903.08	912.00
average		898.39		903.32	
$r_{c,rel}$		-0.41		-1.11	

Table 34: 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
09:02:00	80	210.27	209.21	211.41	209.21
09:03:00	80	210.27	209.21	211.41	209.21
09:04:00	80	210.43	209.21	211.41	209.21
09:05:00	80	210.59	209.21	211.57	209.21
09:06:00	80	210.59	209.21	211.74	209.21
average		210.43		211.51	
$r_{c,rel}$		-0.42		-0.33	
09:12:00	40	104.07	104.60	104.56	104.60
09:13:00	40	104.07	104.60	104.56	104.60
09:14:00	40	104.07	104.60	104.56	104.60
09:15:00	40	104.07	104.60	104.56	104.60
09:16:00	40	104.07	104.60	104.56	104.60
average		104.07		104.56	
$r_{c,rel}$		-0.85		-0.72	
09:22:00	0	-0.16	0.00	-0.49	0.00
09:23:00	0	-0.16	0.00	-0.49	0.00
09:24:00	0	-0.16	0.00	-0.49	0.00
09:25:00	0	-0.16	0.00	-0.49	0.00
09:26:00	0	-0.16	0.00	-0.49	0.00
average		-0.16		-0.49	
r_z					
09:32:00	60	156.93	156.90	157.58	156.90
09:33:00	60	157.09	156.90	157.58	156.90
09:34:00	60	157.09	156.90	157.74	156.90
09:35:00	60	157.25	156.90	157.74	156.90
09:36:00	60	157.25	156.90	157.74	156.90
average		157.12		157.68	
$r_{c,rel}$		-0.65		-0.69	
09:42:00	20	51.55	52.30	51.71	52.30
09:43:00	20	51.55	52.30	51.71	52.30
09:44:00	20	51.55	52.30	51.71	52.30
09:45:00	20	51.55	52.30	51.71	52.30
09:46:00	20	51.55	52.30	51.71	52.30
average		51.55		51.71	
$r_{c,rel}$		-0.46		-0.32	
09:52:00	95	253.01	248.43	253.82	248.43
09:53:00	95	253.01	248.43	253.82	248.43
09:54:00	95	253.01	248.43	253.99	248.43
09:55:00	95	253.01	248.43	253.99	248.43
09:56:00	95	253.01	248.43	253.99	248.43
average		253.01		253.92	
$r_{c,rel}$		0.73		0.66	

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.

The test was also carried out for the NO_2 component 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 the sample gas pressure for NO

	requirement	device 1		device 2	
sensitivity coeff. sample gas pressure b_{gp} [nmol/mol/kPa]	≤ 8.0	0.23	✓	0.17	✓

Table 36: Sensitivity coefficient to the sample gas pressure for NO_2

	requirement	device 1		device 2	
sensitivity coeff. sample gas pressure b_{gp} [nmol/mol/kPa]	≤ 8.0	0.10	✓	0.08	✓

7.5 Assessment

For NO, the sensitivity coefficient to sample gas pressure was 0.23 nmol/mol/kPa for instrument 1; for instrument 2 it was 0.17 nmol/mol/kPa.

For NO_2, the sensitivity coefficient to sample gas pressure was 0.10 nmol/mol/kPa for instrument 1; for instrument 2 it was 0.08 nmol/mol/kPa.

Criterion satisfied? yes

7.6 Detailed presentation of test results

Table 37: Individual values of the sensitivity to the sample gas pressure for NO

			device 1	device 2
time	pressure [kPa]	concentration	[nmol/mol]	[nmol/mol]
09:54:00	80	710.00	708.87	712.48
09:55:00	80	710.00	705.87	713.08
09:56:00	80	710.00	706.47	711.28
average C_{P1}			707.07	712.28
10:10:00	110	710.00	714.29	716.69
10:11:00	110	710.00	713.68	717.89
10:12:00	110	710.00	713.68	717.29
average C_{P2}			713.88	717.29

Table 38: Individual values of the sensitivity to the sample gas pressure for NO_2

time	pressure [kPa]	concentration	device 1 [nmol/mol]	device 2 [nmol/mol]
08:57:00	80	200.00	206.63	207.60
08:58:00	80	200.00	206.95	208.24
08:59:00	80	200.00	206.63	208.56
average C_{P1}			206.74	208.13
09:23:00	110	200.00	209.52	210.49
09:24:00	110	200.00	209.52	210.49
09:25:00	110	200.00	210.17	210.81
average C_{P2}			209.74	210.60

7.1 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.

The test was also carried out for the NO_2 component 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: Sample gas temperature sensitivity coefficient for NO

	requirement	device 1		device 2	
sensitivity coeff. sample gas temperature b_{gt} [nmol/mol/K]	≤ 3.0	0.09	✓	0.11	✓

Table 40: Sample gas temperature sensitivity coefficient for NO_2

	requirement	device 1		device 2	
sensitivity coeff. sample gas temperature b_{gt} [nmol/mol/K]	≤ 3.0	0.01	✓	0.01	✓

7.5 Assessment

For instrument 1, the sensitivity coefficient to sample gas temperature was 0.09 nmol/mol/K for NO; for NO_2, it was 0.11 nmol/mol/K.

For instrument 2, the sensitivity coefficient to sample gas temperature was 0.01 nmol/mol/K for NO; for NO_2, it was 0.01 nmol/mol/K.

Criterion satisfied? yes

7.6 Detailed presentation of test results

Table 41: Individual values of the influence of the sample gas temperature for NO

			device 1	device 2
time	temp [ºC]	concentration	[nmol/mol]	[nmol/mol]
10:12:00	0	710.00	708.27	708.27
10:13:00	0	710.00	708.87	711.28
10:14:00	0	710.00	708.27	710.08
average $C_{GT,1}$			708.47	709.88
13:12:00	30	710.00	711.88	713.68
13:13:00	30	710.00	710.68	711.88
13:14:00	30	710.00	711.28	714.29
average $C_{GT,2}$			711.28	713.28

Table 42: Individual values of the influence of the sample gas temperature for NO_2

time	temp [ºC]	concentration	device 1 [nmol/mol]	device 2 [nmol/mol]
10:19:00	0	200.00	203.42	203.58
10:20:00	0	200.00	203.42	203.74
10:21:00	0	200.00	203.58	204.07
average $C_{GT,1}$			203.47	203.80
13:20:00	30	200.00	203.74	204.23
13:21:00	30	200.00	203.91	204.07
13:22:00	30	200.00	203.74	204.23
average $C_{GT,2}$			203.80	204.18

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_l = 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.

The test was also carried out for the NO_2 component 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 ambient temperature for NO

	requirements	device 1		device 2	
sensitivity coefficient at 0 °C for zero level [nmol/mol/K]	≤ 3.0	0.000	✓	0.040	✓
sensitivity coefficient at 30 °C for zero level [nmol/mol/K]	≤ 3.0	0.010	✓	0.010	✓
sensitivity coefficient at 0 °C for span level [nmol/mol/K]	≤ 3.0	0.030	✓	0.075	✓
sensitivity coefficient at 30 °C for span level [nmol/mol/K]	≤ 3.0	0.952	✓	0.451	✓

Table 44: Sensitivity coefficients to ambient temperature for NO_2

	requirements	device 1		device 2	
sensitivity coefficient at 0 °C for zero level [nmol/mol/K]	≤ 3.0	0.003	✓	0.029	✓
sensitivity coefficient at 30 °C for zero level [nmol/mol/K]	≤ 3.0	0.011	✓	0.016	✓
sensitivity coefficient at 0 °C for span level [nmol/mol/K]	≤ 3.0	0.231	✓	0.241	✓
sensitivity coefficient at 30 °C for span level [nmol/mol/K]	≤ 3.0	0.019	✓	0.024	✓

As can be seen in Table 43 and in Table 44, the sensitivity coefficient of the ambient temperature at the zero and span point meets the performance requirements.

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 0.952 nmol/mol/K for instrument 1 and 0.451 nmol/mol/K for instrument 2.

For NO_2, this would be 0.231 nmol/mol/K for instrument 1 and 0.241 nmol/mol/K for instrument 2.

Criterion satisfied? yes

7.6 Detailed presentation of test results

The individual test results are presented in Table 45 and in Table 46.

Table 45: Results of the sensitivity coefficient to the 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]
03.11.2020	08:55:00	20	0.0	0.0	09:23:00	20	707.7	708.3
03.11.2020	08:56:00	20	0.0	0.0	09:24:00	20	708.9	706.5
03.11.2020	08:57:00	20	0.0	0.0	09:25:00	20	704.1	706.5
average ($X_{1(TS1)}$)			0.0	0.0			706.9	707.1
03.11.2020	16:12:00	0	0.0	0.6	16:24:00	0	708.9	708.9
03.11.2020	16:13:00	0	0.0	1.2	16:25:00	0	707.7	708.3
03.11.2020	16:14:00	0	0.0	0.6	16:26:00	0	707.7	705.9
average($X_{Ts,1}$)		0	0.0	0.8			708.1	707.7
04.11.2020	08:27:00	20	0.0	0.0	08:40:00	20	708.9	711.9
04.11.2020	08:28:00	20	0.0	0.0	08:41:00	20	708.3	708.3
04.11.2020	08:29:00	20	0.0	0.0	08:42:00	20	707.1	713.7
average ($X_{2(TS1)}$) = ($X_{1(TS2)}$)			0.0	0.0			708.1	711.3
04.11.2020	16:38:00	30	0.0	0.0	16:44:00	30	716.1	714.3
04.11.2020	16:39:00	30	0.0	0.0	16:45:00	30	717.9	714.3
04.11.2020	16:40:00	30	0.0	0.0	16:46:00	30	719.1	717.3
average($X_{Ts,2}$)			0.0	0.0			717.7	715.3
05.11.2020	07:56:00	20	0.6	0.6	08:09:00	20	708.3	714.3
05.11.2020	07:57:00	20	0.0	0.0	08:10:00	20	708.9	707.7
05.11.2020	07:58:00	20	0.0	0.0	08:11:00	20	707.7	708.9
average ($X_{2(TS2)}$)			0.2	0.2			708.3	710.3

Table 46: Results of the sensitivity coefficient to the ambient 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]
03.11.2020	08:55:00	20	0.0	0.2	09:14:00	20	204.6	204.4
03.11.2020	08:56:00	20	0.0	0.0	09:15:00	20	205.5	205.2
03.11.2020	08:57:00	20	0.0	0.0	09:16:00	20	206.5	206.2
average ($X_{1(TS1)}$)			0.0	0.1			205.5	205.3
03.11.2020	16:12:00	0	0.0	-0.5	16:18:00	0	200.3	200.0
03.11.2020	16:13:00	0	0.0	-0.7	16:19:00	0	199.2	199.2
03.11.2020	16:14:00	0	0.0	-0.7	16:20:00	0	199.3	200.0
average($X_{Ts,1}$)		0	0.0	-0.6			199.6	199.7
04.11.2020	08:27:00	20	0.2	0.0	08:34:00	20	202.3	203.1
04.11.2020	08:28:00	20	0.2	-0.2	08:35:00	20	202.9	203.6
04.11.2020	08:29:00	20	0.0	-0.2	08:36:00	20	203.6	204.7
average ($X_{2(TS1)}$) = ($X_{1(TS2)}$)			0.1	-0.1			202.9	203.8
04.11.2020	16:38:00	30	0.0	0.0	16:45:00	30	201.8	202.8
04.11.2020	16:39:00	30	0.0	0.0	16:46:00	30	203.1	203.9
04.11.2020	16:40:00	30	0.0	0.0	16:47:00	30	205.2	205.9
average($X_{Ts,2}$)			0.0	0.0			203.4	204.2
05.11.2020	07:56:00	20	0.2	-0.2	08:03:00	20	202.8	203.3
05.11.2020	07:57:00	20	0.2	-0.2	08:04:00	20	203.1	203.9
05.11.2020	07:58:00	20	0.0	-0.3	08:05:00	20	204.4	205.0
average ($X_{2(TS2)}$)			0.1	-0.2			203.4	204.1

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.

The test was also carried out for the NO_2 component 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	0.01	✓	0.01	✓
sensitivity coeff. of voltage b_v at span level [nmol/mol/V]	≤ 0.3	0.02	✓	0.01	✓

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 0.02 nmol/mol/V for instrument 1 and 0.01 nmol/mol/V for instrument 2.

Criterion satisfied? yes

7.6 Detailed presentation of test results

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

time	voltage [V]	concentration	device 1 [nmol/mol]	device 2 [nmol/mol]
11:37:00	207	0	-0.60	0.00
11:38:00	207	0	-0.60	0.00
11:39:00	207	0	0.00	0.00
average C_{V1} at zero			-0.40	0.00
11:47:00	253	0	0.00	0.00
11:48:00	253	0	0.00	0.00
11:49:00	253	0	0.00	-0.60
average C_{V2} at zero			0.00	-0.20
12:07:00	207	710.00	708.27	710.68
12:08:00	207	710.00	707.67	710.08
12:09:00	207	710.00	708.21	709.48
average C_{V1} at Span			708.05	710.08
12:17:00	253	710.00	708.27	710.68
12:18:00	253	710.00	707.67	710.08
12:19:00	253	710.00	708.87	710.08
average C_{V2} at Span			708.27	710.28

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

time	voltage [V]	concentration	device 1 [nmol/mol]	device 2 [nmol/mol]
11:37:00	207	0	0.16	0.16
11:38:00	207	0	0.16	0.16
11:39:00	207	0	0.16	0.00
average C_{V1} at zero			0.16	0.11
11:47:00	253	0	0.00	-0.16
11:48:00	253	0	-0.16	-0.16
11:49:00	253	0	-0.16	-0.16
average C_{V2} at zero			-0.11	-0.16
11:50:00	207	205.00	205.37	206.52
11:51:00	207	205.00	205.37	206.84
11:52:00	207	205.00	205.21	206.03
average C_{V1} at Span			205.32	206.46
11:53:00	253	205.00	206.19	207.01
11:54:00	253	205.00	206.03	207.17
11:55:00	253	205.00	206.03	207.17
average C_{V2} at Span			206.08	207.11

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 inTable 51. The influence of each interferent shall be determined separately. The concentration of the measured variable shall be corrected for the dilution flux due to the addition of the interfering component (e.g. water vapour).

After setting the system at zero and at span level, a mixture of zero gas and the interfering component to be tested is applied at the concentration given in 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 measured variable at the concentration c_t and the interfering component to be investigated. The influence quantities at zero and concentration c_t are calculated from:

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

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

Where:

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

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

$X_{\text{int},ct}$ 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 (500 ppb). 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.

The test was also carried out for the component NO_2 at the zero point and at a span concentration at the level of the 1-h limit value of NO_2 (104 nmol/mol).

Since the measuring system does not operate according to the specified EU reference procedure, the influence of other possible interfering components in normal ambient air was checked in addition to the 3 interfering components specified in EN 14211. The results of the additional test are presented in chapter 6.1 7.4.11 Cross-sensitivity.

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	0.00	✓	-0.60	✓
influence quantity interferent H_2O at c_t [nmol/mol/V]	≤ 5.0 nmol/mol	0.40	✓	1.60	✓
influence quantity interferent CO_2 at zero [nmol/mol/V]	≤ 5.0 nmol/mol	0.40	✓	0.40	✓
influence quantity interferent CO_2 at c_t [nmol/mol/V]	≤ 5.0 nmol/mol	1.80	✓	0.80	✓
influence quantity interferent NH_3 at zero [nmol/mol/V]	≤ 5.0 nmol/mol	0.60	✓	1.00	✓
influence quantity interferent NH3 at c_t [nmol/mol/V]	≤ 5.0 nmol/mol	1.20	✓	1.40	✓

Table 53: Influence of the tested interferents for NO_2 (c_t = ca. 104 nmol/mol)

	requirements	**device 1**		**device 2**	
influence quantity interferent H_2O at zero [nmol/mol/V]	≤ 5.0 nmol/mol	0.27	✓	0.00	✓
influence quantity interferent H_2O at c_t [nmol/mol/V]	≤ 5.0 nmol/mol	0.33	✓	0.22	✓
influence quantity interferent CO_2 at zero [nmol/mol/V]	≤ 5.0 nmol/mol	0.00	✓	-0.21	✓
influence quantity interferent CO_2 at c_t [nmol/mol/V]	≤ 5.0 nmol/mol	0.70	✓	0.76	✓
influence quantity interferent NH_3 at zero [nmol/mol/V]	≤ 5.0 nmol/mol	0.00	✓	-0.16	✓
influence quantity interferent NH3 at c_t [nmol/mol/V]	≤ 5.0 nmol/mol	1.09	✓	0.98	✓

7.5 Assessment

For NO at zero point the result for the interference were 0.00 nmol/mol (AMS 1) and -0.60 nmol/mol (AMS 2) for H_2O, 0.40 nmol/mol (AMS 1) and 0.40 nmol/mol (AMS 2) for CO_2 and finally 0.60 nmol/mol (AMS 1) and 1.00 nmol/mol (AMS 2) for NH_3. For NO_2 at zero point the result for the interference were 0.27 nmol/mol (AMS 1) and 0.00 nmol/mol (AMS 2) for H_2O, 0.00 nmol/mol (AMS 1) and -0.21 nmol/mol (AMS 2) for CO_2 and finally 0.00 nmol/mol (AMS 1) and -0.16 nmol/mol (AMS 2) for NH_3.

The following results were obtained for the cross-sensitivity at the limit value c_t: NO: 0.40 nmol/mol for instrument 1 and 1.60 nmol/mol for instrument 2; H_2O: 1.80 nmol/mol for instrument 1 and 0.80 nmol/mol for instrument 2; CO_2 and 1.20 nmol/mol for instrument 1 and 1.40 nmol/mol at NH_3. The following results were obtained for the cross-sensitivity at the limit value c_t: NO_2: 0.33 nmol/mol for instrument 1 and 0.22 nmol/mol for instrument 2; H_2O: 0.70 nmol/mol for instrument 1 and 0.76 nmol/mol for instrument 2; CO_2 and 1.09 nmol/mol for instrument 1 and 0.98 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)	13:14:00	0.00	0.00	13:29:00	0.00	-0.60
	13:15:00	0.00	0.00	13:30:00	0.00	-0.60
	13:16:00	0.00	0.00	13:31:00	0.00	-0.60
	average x_z	0.00	0.00	average x_z	0.00	-0.60
test gas c_t + H_2O (19 mmol/mol)	13:45:00	504.45	508.06	14:00:00	507.46	508.66
	13:46:00	506.85	507.46	14:01:00	508.66	506.85
	13:47:00	508.06	504.45	14:02:00	504.45	509.26
	average x_{ct}	506.45	506.65	average x_{ct}	506.85	508.26
zero gas + CO_2 (500 µmol/mol)	08:14:00	0.60	0.00	08:24:00	0.60	0.00
	08:15:00	0.60	0.00	08:25:00	0.60	0.00
	08:16:00	0.00	0.00	08:26:00	1.20	1.20
	average x_z	0.40	0.00	average x_z	0.80	0.40
test gas c_t + CO_2 (500 µmol/mol)	08:34:00	500.24	501.44	08:44:00	502.04	502.65
	08:35:00	500.24	502.04	08:45:00	501.44	502.04
	08:36:00	499.64	500.84	08:46:00	502.04	502.04
	average x_{ct}	500.04	501.44	average x_{ct}	501.84	502.24
zero gas + NH_3 (200 nmol/mol)	09:45:00	0.60	0.00	09:55:00	1.20	1.20
	09:46:00	0.60	0.00	09:56:00	1.20	1.20
	09:47:00	0.60	0.60	09:57:00	1.20	1.20
	average x_z	0.60	0.20	average x_z	1.20	1.20
test gas c_t + NH_3 (200 nmol/mol)	10:15:00	503.25	506.25	10:25:00	505.05	506.85
	10:16:00	503.25	505.65	10:26:00	504.45	507.46
	10:17:00	503.85	506.25	10:27:00	504.45	508.06
	average x_{ct}	504.65	506.05	average x_{ct}	504.65	507.46

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)	13:14:00	0.16	0.33	13:29:00	0.33	0.33
	13:15:00	0.00	0.33	13:30:00	0.33	0.33
	13:16:00	0.00	0.33	13:31:00	0.33	0.33
	average x_z	0.05	0.33	average x_z	0.33	0.33
test gas c_t + H_2O (19 mmol/mol)	14:35:00	106.03	106.52	14:51:00	106.36	106.68
	14:36:00	106.19	106.52	14:52:00	106.52	106.68
	14:37:00	106.36	106.68	14:53:00	106.68	107.01
	average x_{ct}	106.19	106.58	average x_{ct}	106.52	106.79
zero gas + CO_2 (500 µmol/mol)	11:24:00	-0.16	-0.33	11:40:00	-0.16	-0.65
	11:25:00	-0.16	-0.49	11:41:00	-0.16	-0.65
	11:26:00	-0.16	-0.49	11:42:00	-0.16	-0.65
	average x_z	-0.16	-0.44	average x_z	-0.16	-0.65
test gas c_t + CO_2 (500 µmol/mol)	11:54:00	105.71	105.38	12:09:00	106.36	106.19
	11:55:00	105.71	105.71	12:10:00	106.52	106.36
	11:56:00	105.87	105.71	12:11:00	106.52	106.52
	average x_{ct}	105.76	105.60	average x_{ct}	106.47	106.36
zero gas + NH_3 (200 nmol/mol)	12:25:00	-0.16	-0.82	12:40:00	-0.16	-0.98
	12:26:00	-0.16	-0.82	12:41:00	-0.16	-0.98
	12:27:00	-0.16	-0.82	12:42:00	-0.16	-0.98
	average x_z	-0.16	-0.82	average x_z	-0.16	-0.98
test gas c_t + NH_3 (200 nmol/mol)	12:55:00	106.85	106.68	13:10:00	107.99	107.83
	12:56:00	107.01	107.01	13:11:00	108.15	107.83
	12:57:00	107.17	107.01	13:12:00	108.15	107.99
	average x_{ct}	108.10	106.90	average x_{ct}	108.10	107.88

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 $c_{t,NO2}$ 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} is the average of the at least four independent measurements during the variable concentration period;

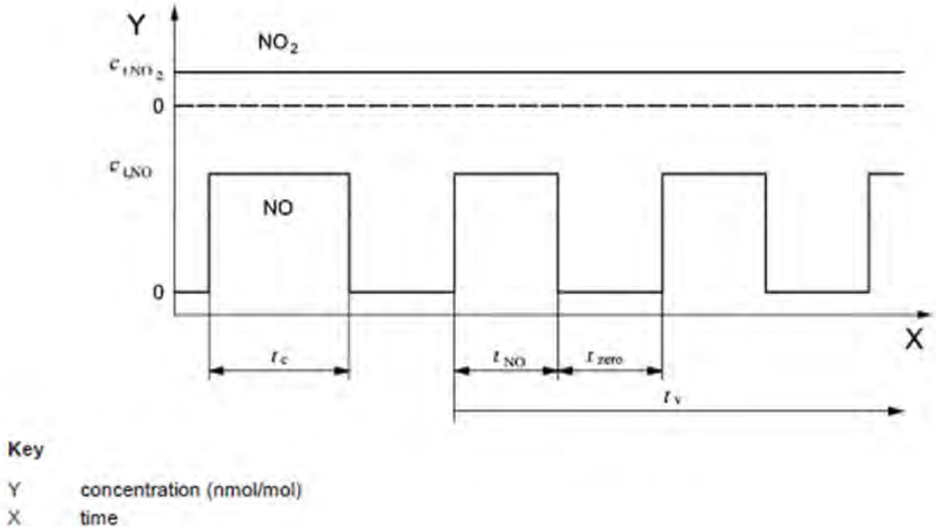


Figure 15: Test of the averaging effect (t_{NO} = t_{zero} = 45 s.)

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 $c_{t,NO2}$ 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.

The test was also carried out for the component NO_2 between zero and a span concentration at the level of the 1-h limit value of 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%	3.1	✓	-2.9	✓

This results in the following averaging effects:

System 1: 3.1%

System 2: -2.9 %

Table 57: Results of the averaging test for NO_2

	requirement	device 1		device 2	
averaging effect E_{av} [%]	≤ 7%	0.7	✓	3.2	✓

This results in the following averaging effects:

System 1: 0.7%

System 2: 3.2%

7.5 Assessment

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

Criterion satisfied? yes

7.6 Detailed presentation of test results

In Table 58 and in Table 59 the individual results of the averaging tests are presented.

Table 58: Results of the averaging tests for NO

		device 1	device 2
	time	[nmol/mol]	[nmol/mol]
average constant concentration $C_{av,c}$	11:34:00 till 11:53:00	602.0	615.5
average variable concentration $C_{av,c}$	11:54:00 till 12:13:00	298.9	311.3

		device 1	device 2
	time	[nmol/mol]	[nmol/mol]
average constant concentration $C_{av,c}$	12:24:00 till 12:43:00	605.8	617.6
average variable concentration $C_{av,c}$	12:44:00 till 13:03:00	293.2	314.5

		device 1	device 2
	time	[nmol/mol]	[nmol/mol]
average constant concentration $C_{av,c}$	13:15:00 till 13:34:00	607.1	617.8
average variable concentration $C_{av,c}$	13:35:00 till 13:54:00	287.0	326.0

Table 59: Results of the averaging tests for NO_2

		device 1	device 2
	time	[nmol/mol]	[nmol/mol]
average constant concentration $C_{av,c}$	07:48:00 till 08_07	101.9	102.0
average variable concentration $C_{av,c}$	08:08:00 till 08:27:00	53.0	49.7

		device 1	device 2
	time	[nmol/mol]	[nmol/mol]
average constant concentration $C_{av,c}$	08:39:00 till 08:58:00	102.8	102.9
average variable concentration $C_{av,c}$	08:59:00 till 09:18:00	50.9	49.2

		device 1	device 2
	time	[nmol/mol]	[nmol/mol]
average constant concentration $C_{av,c}$	09:25:00 till 09:44:00	103.3	103.4
average variable concentration $C_{av,c}$	09:45:00 till 10:04:00	49.1	50.3

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 test was performed in compliance with the requirements specified in EN 14211. During the test, the gas path was switched between sample gas and span gas inlet using a three-way valve.

7.4 Evaluation

During the test, the following differences between sample and calibration port were determined:

Table 60: Results of the difference between sample/calibration inlet for NO

	requirement	device 1		device 2	
difference sample/calibration port Δx_{cs} [%]	≤ 1%	0.14	✓	0.06	✓

Table 61: Results of the difference between sample/calibration inlet for NO_2

	requirement	device 1		device 2	
difference sample/calibration port Δx_{cs} [%]	≤ 1%	-0.14	✓	-0.33	✓

7.5 Assessment

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

Criterion satisfied? yes

7.6 Detailed presentation of test results

Not applicable

Table 62: Results for testing the difference between sample and calibration port for NO

		device 1	device 2
	time	[nmol/mol]	[nmol/mol]
calibration port	10:17:00	711.3	714.9
	10:18:00	710.7	714.3
	10:19:00	711.3	713.7
sample port	10:31:00	710.1	714.3
	10:32:00	710.1	714.3
	10:33:00	710.1	713.1

Table 63: Results for testing the difference between sample and calibration port for NO_2

		device 1	device 2
	time	[nmol/mol]	[nmol/mol]
calibration port	10:47:00	207.0	208.5
	10:48:00	206.7	207.8
	10:49:00	206.2	207.7
sample port	10:57:00	207.0	208.6
	10:58:00	206.7	208.6
	10:59:00	207.0	208.6

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 NOx 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 NOx channel. Then, NO is brought to react with O_3 to produce NO_2. This mixture containing a constant NOx 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 NOx 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 N500 measuring system does not work according to the EU standard reference method of chemiluminescence. Therefore, the measuring system does not have a standard NO-NO_2 converter. The N500 measuring system analyses NO_2 directly in the UV range. NO is determined by oxidising the sample air with ozone in alternating cycles. The difference between the two measurements is displayed as NO value. Even if there is no converter in the measuring system to be tested, the test was carried out as indicated above to show that the 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 testing, the following converter efficiencies were determined for the two N500 measuring systems. The lowest value of the two NO_2 concentration is reported below.

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

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 64 presents the individual values.

Table 64: 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]
	12:30:00	s t a r t					
O_3=0, NO=50%	12:47:00	0.0	0.0	477.4	490.0	479.8	489.4
	12:48:00	0.0	0.0	475.6	488.2	479.8	489.4
	12:49:00	0.0	0.0	475.6	488.2	479.8	489.4
	12:50:00	0.0	0.0	475.6	488.2	479.8	489.4
average		0.0	0.0	476.0	488.7	479.8	489.4
NO_2= 50%	13:11:00	130.0	130.5	350.5	488.2	354.7	490.0
	13:12:00	130.0	130.0	349.9	488.2	354.1	488.8
130.75	13:13:00	130.0	129.3	350.5	488.2	354.1	488.8
	13:14:00	130.0	129.3	349.9	488.2	354.1	488.8
average		130.0	129.7	350.2	488.2	354.3	489.1
O_3=0, NO=50%	14:15:00	0.0	0.0	477.4	488.2	479.8	490.6
	14:16:00	0.0	0.0	475.6	488.2	479.8	490.0
	14:17:00	0.0	0.0	475.6	491.2	479.8	487.0
	14:18:00	0.0	0.0	475.6	488.8	481.0	490.0
average		0.0	0.0	476.0	489.1	480.1	489.4
NO_2= 95%	14:39:00	248.0	248.5	238.7	488.8	236.3	488.8
	14:40:00	248.0	248.5	236.9	488.2	234.5	490.6
248.43	14:41:00	248.0	248.6	235.1	488.2	233.9	490.0
	14:42:00	248.0	248.7	239.9	491.2	233.3	487.0
average		248.0	248.6	237.6	489.1	234.5	489.1
O_3=0, NO=50%	14:55:00	0.0	0.0	484.0	488.8	483.4	488.2

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 N500 measuring system is approximately 30.0 ml from the sample inlet to the measuring cell. The typical sample gas flow is at 1.0 l/min. This results in a residence time in the analyser of 1.9 s.

7.4 Evaluation

Not applicable.

7.5 Assessment

Residence time in the analyser was 1.9 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;

$C_{S,0}$ 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 65 and Table 66 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.

The test was also carried out for the NO_2 component at a concentration level of 70 % to 80 % of the certification range for NO_2.

7.4 Evaluation

Table 65: Results for the long-term drift at zero point for NO

		requierment	Device 1		Device 2	
average start $Cz_{,1}$ at zero [nmol/mol]	09.11.2020	≤ 5.0	--	✓	--	✓
long term drift $D_{L,Z}$ at zero [nmol/mol]	23.11.2020	≤ 5.0	0.04	✓	-0.36	✓
long term drift $D_{L,Z}$ at zero [nmol/mol]	07.12.2020	≤ 5.0	-0.80	✓	-0.48	✓
long term drift $D_{L,Z}$ at zero [nmol/mol]	18.12.2020	≤ 5.0	-0.92	✓	-0.36	✓
long term drift $D_{L,Z}$ at zero [nmol/mol]	04.01.2021	≤ 5.0	0.88	✓	0.48	✓
long term drift $D_{L,Z}$ at zero [nmol/mol]	18.01.2021	≤ 5.0	0.76	✓	0.60	✓
long term drift $D_{L,Z}$ at zero [nmol/mol]	01.02.2021	≤ 5.0	0.64	✓	1.08	✓
long term drift $D_{L,Z}$ at zero [nmol/mol]	15.02.2021	≤ 5.0	0.76	✓	0.84	✓

Table 66: Results for the long-term drift at span point for NO

		requierment	Device 2 1		Device 2	
average start $Cs_{,1}$ at span [nmol/mol]	09.11.2020	≤ 5 %	--	✓	--	✓
long term drift $D_{L,S}$ at span [nmol/mol]	23.11.2020	≤ 5 %	0.13	✓	0.07	✓
long term drift $D_{L,S}$ at span [nmol/mol]	07.12.2020	≤ 5 %	-0.24	✓	-0.17	✓
long term drift $D_{L,S}$ at span [nmol/mol]	18.12.2020	≤ 5 %	-0.53	✓	-0.49	✓
long term drift $D_{L,S}$ at span [nmol/mol]	04.01.2021	≤ 5 %	0.28	✓	0.33	✓
long term drift $D_{L,S}$ at span [nmol/mol]	18.01.2021	≤ 5 %	0.43	✓	0.33	✓
long term drift $D_{L,S}$ at span [nmol/mol]	01.02.2021	≤ 5 %	0.66	✓	0.74	✓
long term drift $D_{L,S}$ at span [nmol/mol]	15.02.2021	≤ 5 %	0.93	✓	1.02	✓

Table 67: Results for the long-term drift at zero point for NO_2

		requierment	Device 1		Device 2	
average start $Cz_{,1}$ at zero [nmol/mol]	09.11.2020	≤ 5.0	--	✓	--	✓
long term drift $D_{L,Z}$ at zero [nmol/mol]	23.11.2020	≤ 5.0	0.19	✓	0.17	✓
long term drift $D_{L,Z}$ at zero [nmol/mol]	07.12.2020	≤ 5.0	0.43	✓	0.07	✓
long term drift $D_{L,Z}$ at zero [nmol/mol]	18.12.2020	≤ 5.0	-0.03	✓	-0.05	✓
long term drift $D_{L,Z}$ at zero [nmol/mol]	04.01.2021	≤ 5.0	0.75	✓	0.87	✓
long term drift $D_{L,Z}$ at zero [nmol/mol]	18.01.2021	≤ 5.0	0.31	✓	0.47	✓
long term drift $D_{L,Z}$ at zero [nmol/mol]	01.02.2021	≤ 5.0	0.09	✓	0.57	✓
long term drift $D_{L,Z}$ at zero [nmol/mol]	15.02.2021	≤ 5.0	0.73	✓	0.47	✓

Table 68: Results for the long-term drift at span point for NO_2

		requierment	Device 2 1		Device 2	
average start $Cs_{,1}$ at span [nmol/mol]	09.11.2020	≤ 5 %	--	✓	--	✓
long term drift $D_{L,S}$ at span [nmol/mol]	23.11.2020	≤ 5 %	1.26	✓	1.22	✓
long term drift $D_{L,S}$ at span [nmol/mol]	07.12.2020	≤ 5 %	2.09	✓	1.81	✓
long term drift $D_{L,S}$ at span [nmol/mol]	18.12.2020	≤ 5 %	-0.04	✓	0.74	✓
long term drift $D_{L,S}$ at span [nmol/mol]	04.01.2021	≤ 5 %	2.29	✓	2.05	✓
long term drift $D_{L,S}$ at span [nmol/mol]	18.01.2021	≤ 5 %	1.96	✓	1.46	✓
long term drift $D_{L,S}$ at span [nmol/mol]	01.02.2021	≤ 5 %	1.26	✓	1.58	✓
long term drift $D_{L,S}$ at span [nmol/mol]	15.02.2021	≤ 5 %	1.22	✓	1.95	✓

7.5 Assessment

Maximum long-term drift at zero point $D_{l,z}$ for NO was at -0.92 nmol/mol for instrument 1 and 1.08 nmol/mol for instrument 2. Maximum long-term drift at span point $D_{l,s}$ for NO was at 0.93% for instrument 1 and 1.02% for instrument 2.

Maximum long-term drift at zero point $D_{l,z}$ for NO_2 was at 0.75 nmol/mol for instrument 1 and 0.87 nmol/mol for instrument 2. Maximum long-term drift at span point $D_{l,s}$ for NO_2 was at 2.29% for instrument 1 and 2.05% for instrument 2.

Criterion satisfied? yes

7.6 Detailed presentation of test results

The individual test results for the determination of the long-term drift are shown in Table 69 and in Table 70.

Table 69: Results of the drift test for NO

Zero Concentration			
		Device 1	Device 2
Date	Time	[nmol/mol]	[nmol/mol]
09.11.2020	13:54:00	0.60	0.60
	13:55:00	0.60	0.60
	13:56:00	0.60	0.60
	average	0.60	0.60
	13:58:00	0.60	0.60
	13:59:00	0.60	0.60
	14:00:00	0.60	0.60
	average	0.60	0.60
	14:02:00	1.20	0.60
	14:03:00	0.60	0.00
	14:04:00	0.00	0.60
	average	0.60	0.40
	14:06:00	0.00	0.00
	14:07:00	0.00	0.00
	14:08:00	-0.60	0.00
	average	-0.20	0.00
	14:10:00	0.00	0.00
	14:11:00	0.00	0.60
	14:12:00	0.00	0.00
	average	0.00	0.20
Average field start $c_{z,0}$		**0.32**	**0.36**
23.11.2020	10:10:00	0.60	0.00
	10:11:00	0.60	0.00
	10:12:00	0.00	0.00
	10:13:00	0.00	0.00
	10:14:00	0.60	0.00
	aver. $c_{z,1}$	**0.36**	**0.00**
07.12.2020	14:01:00	0.00	0.00
	14:02:00	-0.60	-0.60
	14:03:00	-0.60	-0.60
	14:04:00	-1.20	0.00
	14:05:00	0.00	0.60
	aver. $c_{z,1}$	**-0.48**	**-0.12**
18.12.2020	11:17:00	-0.60	0.00
	11:18:00	-0.60	0.00
	11:19:00	-0.60	0.00
	11:20:00	-0.60	0.00
	11:21:00	-0.60	0.00
	aver. $c_{z,1}$	**-0.60**	**0.00**
04.01.2021	14:19:00	1.20	0.60
	14:20:00	0.00	0.00
	14:21:00	1.80	1.20
	14:22:00	1.20	1.20
	14:23:00	1.80	1.20
	aver. $c_{z,1}$	**1.20**	**0.84**
18.01.2021	12:11:00	1.20	0.60
	12:12:00	1.20	1.20
	12:13:00	0.60	1.20
	12:14:00	1.20	0.60
	12:15:00	1.20	1.20
	aver. $c_{z,1}$	**1.08**	**0.96**
01.02.2021	10:00:00	0.60	1.20
	10:01:00	0.60	1.80
	10:02:00	1.80	1.20
	10:03:00	1.20	1.20
	10:04:00	0.60	1.80
	aver. $c_{z,1}$	**0.96**	**1.44**
15.02.2021	10:29:00	0.60	0.60
	10:30:00	1.20	1.20
	10:31:00	0.60	1.20
	10:32:00	1.20	1.20
	10:33:00	1.80	1.80
	aver. $c_{z,1}$	**1.08**	**1.20**

C_t-Concentration			
		Device 1	Device 2
Date	Time	[nmol/mol]	[nmol/mol]
09.11.2020	14:50:00	720.30	720.90
	14:51:00	720.30	720.30
	14:52:00	719.70	719.70
	average	720.10	720.30
	14:54:00	720.90	720.90
	14:55:00	720.30	720.90
	14:56:00	720.30	720.30
	average	720.50	720.70
	14:58:00	720.30	720.30
	14:59:00	720.90	720.90
	15:00:00	720.30	720.90
	average	720.50	720.70
	15:02:00	719.70	719.70
	15:03:00	720.30	720.30
	15:04:00	720.90	720.90
	average	720.30	720.30
	15:06:00	720.30	720.30
	15:07:00	719.70	719.70
	15:08:00	720.30	720.30
	average	720.10	720.10
Average field start $c_{s,0}$		**720.30**	**720.42**
23.11.2020	10:32:00	720.90	719.70
	10:33:00	720.30	719.10
	10:34:00	722.10	720.30
	10:35:00	722.10	722.10
	10:36:00	720.90	721.50
	aver. $c_{s,1}$	**721.26**	**720.54**
07.12.2020	14:11:00	717.30	718.50
	14:12:00	717.90	718.50
	14:13:00	717.30	719.10
	14:14:00	718.50	719.10
	14:15:00	717.90	718.50
	aver. $c_{s,1}$	**717.78**	**718.74**
18.12.2020	11:28:00	714.90	717.30
	11:29:00	716.10	717.30
	11:30:00	716.10	717.30
	11:31:00	716.10	716.70
	11:32:00	714.90	714.30
	aver. $c_{s,1}$	**715.62**	**716.58**
04.01.2021	14:41:00	722.70	723.30
	14:42:00	723.90	723.90
	14:43:00	723.90	723.30
	14:44:00	723.30	723.90
	14:45:00	722.10	722.10
	aver. $c_{s,1}$	**723.18**	**723.30**
18.01.2021	12:33:00	723.30	722.70
	12:34:00	723.90	723.30
	12:35:00	723.90	722.70
	12:36:00	725.10	723.90
	12:37:00	724.50	724.50
	aver. $c_{s,1}$	**724.14**	**723.42**
01.02.2021	10:22:00	724.50	727.50
	10:23:00	726.30	726.90
	10:24:00	725.70	726.30
	10:25:00	726.30	727.50
	10:26:00	725.70	726.30
	aver. $c_{s,1}$	**725.70**	**726.90**
15.02.2021	10:41:00	728.10	726.30
	10:42:00	728.10	729.30
	10:43:00	727.50	728.70
	10:44:00	727.50	729.30
	10:45:00	728.10	729.90
	aver. $c_{s,1}$	**727.86**	**728.70**

Table 70: Results of the drift test for NO_2

Zero Concentration			
		Device 1	Device 2
Date	Time	[nmol/mol]	[nmol/mol]
09.11.2020	13:54:00	0.20	0.20
	13:55:00	0.20	0.20
	13:56:00	0.20	0.20
	average	0.20	0.20
	13:58:00	0.20	0.20
	13:59:00	0.20	0.20
	14:00:00	0.20	0.20
	average	0.20	0.20
	14:02:00	0.30	0.20
	14:03:00	0.20	0.00
	14:04:00	0.20	0.00
	average	0.23	0.07
	14:06:00	-0.20	0.00
	14:07:00	0.00	0.20
	14:08:00	0.00	0.00
	average	-0.07	0.07
	14:10:00	-0.20	0.20
	14:11:00	-0.20	0.20
	14:12:00	-0.30	0.00
	average	-0.23	0.13
Average field start $c_{z,0}$		**0.07**	**0.13**
23.11.2020	10:10:00	0.30	0.20
	10:11:00	0.30	0.20
	10:12:00	0.30	0.20
	10:13:00	0.20	0.20
	10:14:00	0.20	0.70
	aver. $c_{z,1}$	**0.26**	**0.30**
07.12.2020	14:01:00	0.30	0.20
	14:02:00	0.50	0.20
	14:03:00	0.50	0.20
	14:04:00	0.50	0.20
	14:05:00	0.70	0.20
	aver. $c_{z,1}$	**0.50**	**0.20**
18.12.2020	11:17:00	0.20	0.20
	11:18:00	0.20	0.20
	11:19:00	0.00	0.00
	11:20:00	0.00	0.00
	11:21:00	-0.20	0.00
	aver. $c_{z,1}$	**0.04**	**0.08**
04.01.2021	14:19:00	0.80	1.00
	14:20:00	1.00	0.80
	14:21:00	0.80	1.30
	14:22:00	0.80	1.10
	14:23:00	0.70	0.80
	aver. $c_{z,1}$	**0.82**	**1.00**
18.01.2021	12:11:00	0.50	0.50
	12:12:00	0.30	0.80
	12:13:00	0.30	0.50
	12:14:00	0.50	0.50
	12:15:00	0.30	0.70
	aver. $c_{z,1}$	**0.38**	**0.60**
01.02.2021	10:00:00	0.30	0.20
	10:01:00	-0.20	0.80
	10:02:00	0.30	0.80
	10:03:00	0.20	0.70
	10:04:00	0.20	1.00
	aver. $c_{z,1}$	**0.16**	**0.70**
15.02.2021	10:29:00	1.00	0.20
	10:30:00	0.70	0.50
	10:31:00	0.80	1.00
	10:32:00	0.70	0.50
	10:33:00	0.80	0.80
	aver. $c_{z,1}$	**0.80**	**0.60**

C_t-Concentration			
		Device 1	Device 2
Date	Time	[nmol/mol]	[nmol/mol]
09.11.2020	14:22:00	203.30	202.60
	14:23:00	202.80	202.60
	14:24:00	203.30	203.10
	average	203.13	202.77
	14:26:00	202.80	202.60
	14:27:00	203.60	203.40
	14:28:00	203.30	203.10
	average	203.23	203.03
	14:30:00	203.40	203.30
	14:31:00	203.60	203.30
	14:32:00	203.30	203.10
	average	203.43	203.23
	14:34:00	203.30	203.40
	14:35:00	203.40	203.30
	14:36:00	203.60	203.40
	average	203.43	203.37
	14:38:00	203.30	203.60
	14:39:00	203.40	203.40
	14:40:00	203.60	203.40
	average	203.43	203.47
Average field start $c_{s,0}$		**203.33**	**203.17**
23.11.2020	10:23:00	206.40	206.20
	10:24:00	206.20	206.00
	10:25:00	205.90	205.70
	10:26:00	205.90	205.50
	10:27:00	206.20	205.90
	aver. $c_{s,1}$	**206.12**	**205.86**
07.12.2020	14:28:00	207.50	207.30
	14:29:00	208.00	207.30
	14:30:00	208.30	206.80
	14:31:00	208.30	206.70
	14:32:00	208.50	206.80
	aver. $c_{s,1}$	**208.12**	**206.98**
18.12.2020	11:41:00	203.40	205.20
	11:42:00	203.10	204.70
	11:43:00	203.60	204.70
	11:44:00	203.40	204.40
	11:45:00	202.60	204.20
	aver. $c_{s,1}$	**203.22**	**204.64**
04.01.2021	14:30:00	208.60	208.50
	14:31:00	208.60	208.10
	14:32:00	208.60	208.60
	14:33:00	209.50	207.80
	14:34:00	209.00	208.50
	aver. $c_{s,1}$	**208.86**	**208.30**
18.01.2021	12:22:00	207.70	206.80
	12:23:00	207.50	207.30
	12:24:00	207.70	206.20
	12:25:00	208.00	206.80
	12:26:00	207.70	206.20
	aver. $c_{s,1}$	**207.72**	**206.66**
01.02.2021	10:12:00	205.70	207.00
	10:13:00	206.40	206.80
	10:14:00	206.20	206.80
	10:15:00	205.90	207.30
	10:16:00	205.90	207.20
	aver. $c_{s,1}$	**206.02**	**207.02**
15.02.2021	10:54:00	206.20	208.00
	10:55:00	206.40	207.50
	10:56:00	206.80	208.00
	10:57:00	206.70	207.70
	10:58:00	206.80	207.30
	aver. $c_{s,1}$	**206.58**	**207.70**

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 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 was calculated from the hourly NO_2 averages over the field test period according to the equation stated above.

7.4 Evaluation

Table 71: Reproducibility standard deviation for NO_2 based on complete field test data

reproducibility standard deviation in field		
no. of measurments (1h- average)	[n]	2354
average of both analyzers (3 month)	[nmol/mol]	13.06
standard deviation from paired measurements	[nmol/mol]	0.479
reproducibility standard deviation in field $S_{r,f}$	**[%]**	**3.67**
requirement	≤ 5.0 %	✓

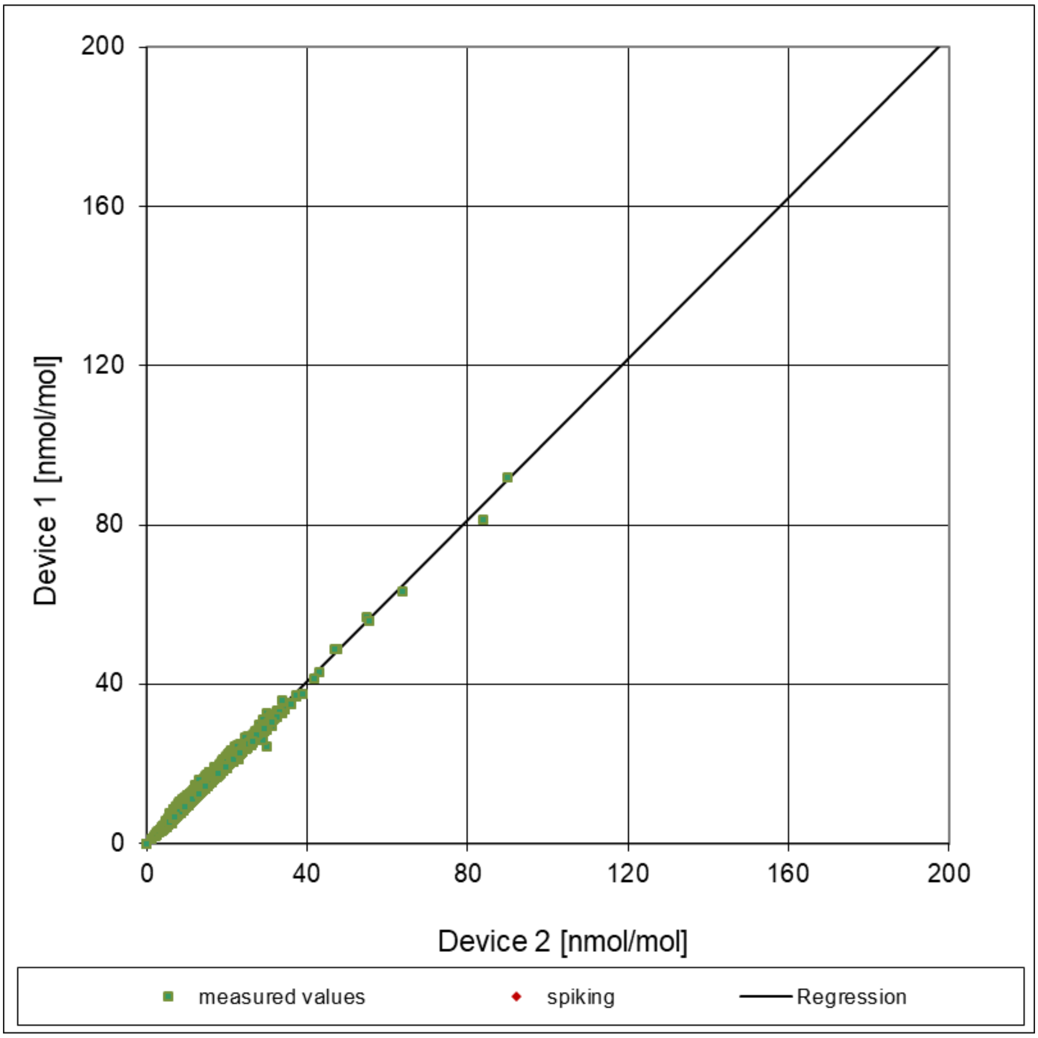


Figure 16: Reproducibility standard deviation for NO_2 under field conditions

The reproducibility standard deviation under field conditions was at 3.67% of the average for NO_2. This value is also used for the calculation of the total uncertainty according to EN 14211.

7.5 Assessment

The reproducibility standard deviation for NO_2 under field conditions was 3.67% as a percentage of the mean value over the three-month field test period. Thus, the requirements of EN 14211 are satisfied.

Criterion satisfied? yes

7.6 Detailed presentation of test results

For the sake of clarity, the results of the reproducibility standard deviation for NO are also given here. According to EN 14211, the evaluation of the reproducibility standard deviation is carried out in the field with NO_2. Therefore, the following data are listed for information only.

Table 72: Reproducibility standard deviation for NO based on complete field test data

reproducibility standard deviation in field		
no. of measurments (1h- average)	[n]	2354
average of both analyzers (3 month)	[nmol/mol]	36.62
standard deviation from paired measurements	[nmol/mol]	0.398
reproducibility standard deviation in field $S_{r,f}$	**[%]**	**1.09**
requirement	≤ 5.0 %	✓

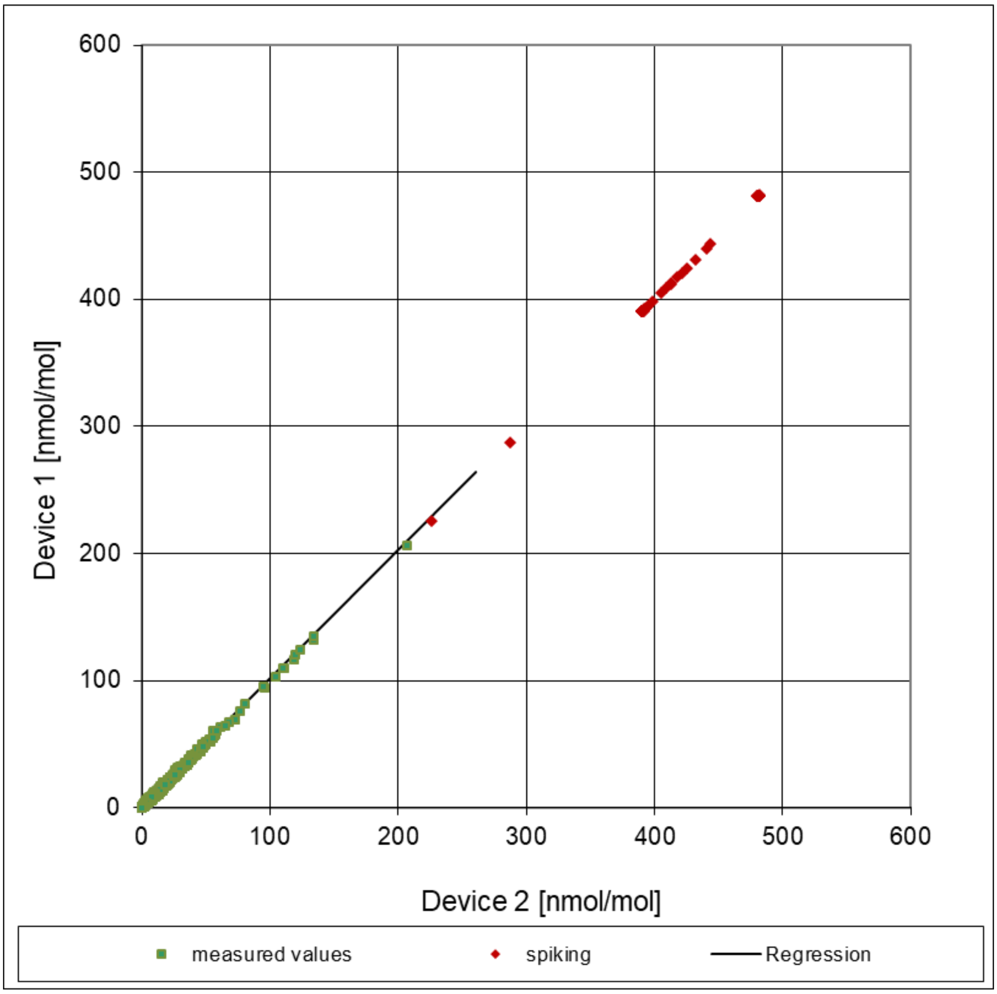


Figure 17: Reproducibility standard deviation for NO under field conditions

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 span 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 month 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 must be changed depending on the dust load at the measuring location. 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 73.

Table 73: Availability of the N500 measuring system

		System 1	System 2
Operation time	h	2354	2354
Outage time	h	0	0
Maintenance time	h	12	12
Actual operating time:	h	2342	2342
Actual operating time incl. maintenance times:	h	2354	2354
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 at 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 74 summarises the results for items 1 and 3.

Table 75 and Table 77 contain the results regarding item 2.

Table 76 and Table 78 contain the results regarding item 4.

Table 74: 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: 0.13 nmol/mol (NO) S_r System 2: 0.13 nmol/mol (NO) S_r System 1: 0.00 nmol/mol (NO_2) S_r System 2: 0.11 nmol/mol (NO_2)	yes	101
8.4.5 Repeatability standard deviation at concentration level c_t	≤ 3.0 nmol/mol	S_r System 1: 1.63 nmol/mol (NO) S_r System 2: 1.34 nmol/mol (NO) S_r System 1: 0.08 nmol/mol (NO_2) S_r System 2: 0.08 nmol/mol (NO_2)	yes	101
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	$X_{l,z}$ System 1: ZP -0.60 nmol/mol X_l System 1: RP 1.72% (NO) $X_{l,z}$ System 2: ZP -0.60 nmol/mol X_l System 2: RP 2.24% (NO) $X_{l,z}$ System 1: ZP -0.16 nmol/mol (NO_2) X_l System 1: RP 0.85% (NO_2) $X_{l,z}$ System 2: ZP -0.49 nmol/mol (NO_2) X_l System 2: RP 0.72% (NO_2)	yes	105
8.4.7 Sensitivity coefficient of sample gas pressure	≤ 8.0 nmol/mol/kPa	b_{gp} System 1: 0.23 nmol/mol/kPa (NO) b_{gp} System 2: 0.17 nmol/mol/kPa (NO) b_{gp} System 1: 0.10 nmol/mol/kPa (NO_2) b_{gp} System 2: 0.08 nmol/mol/kPa (NO_2)	yes	112
8.4.8 Sensitivity coefficient of sample gas temperature	≤ 3.0 nmol/mol/K	b_{gt} System 1: 0.09 nmol/mol/K (NO) b_{gt} System 2: 0.11 nmol/mol/K (NO) b_{gt} System 1: 0.01 nmol/mol/K (NO_2) b_{gt} System 2: 0.01 nmol/mol/K (NO_2)	yes	115
8.4.9 Sensitivity coefficient of surrounding temperature	≤ 3.0 nmol/mol/K	b_{st} System 1: 0.952 nmol/mol/K (NO) b_{st} System 2: 0.451 nmol/mol/K (NO) b_{st} System 1: 0.231 nmol/mol/K (NO_2) b_{st} System 2: 0.241 nmol/mol/K (NO_2)	yes	118

Performance characteristic	**Performance criterion**	**Test result**	**Satisfied**	**Page**
8.4.10 Sensitivity coefficient of electrical voltage	≤ 0.3 nmol/mol/V	b_v System 1: RP 0.01 nmol/mol/V (NO) b_v System 2: RP 0.00 nmol/mol/V (NO) b_v System 1: RP 0.02 nmol/mol/V (NO_2) b_v System 2: RP 0.01 nmol/mol/V (NO_2)	yes	122
8.4.11 Interferent at zero and at concentration level c_t	H_2O ≤ 5.0 nmol/mol CO2 ≤ 5.0 nmol/mol NH_3 ≤ 5.0 nmol/mol	NO duct - H_2O System 1: ZP 0.00 nmol/mol / RP 0.40 nmol/mol System 2: ZP -0.60 nmol/mol / RP 1.60 nmol/mol NO duct - CO_2 System 1: ZP 0.40 nmol/mol / RP 1.80 nmol/mol System 2: ZP 0.40 nmol/mol / RP 0.80 nmol/mol NO duct - NH_3 System 1: ZP 0.60 nmol/mol / RP 1.20 nmol/mol System 2: ZP 1.00 nmol/mol / RP 1.40 nmol/mol NO_2 duct - H_2O System 1: ZP 0.27 nmol/mol / RP 0.33 nmol/mol System 2: ZP 0.00 nmol/mol / RP 0.22 nmol/mol NO_2 duct - CO_2 System 1: ZP 0.00 nmol/mol / RP 0.70 nmol/mol System 2: ZP -0.21 nmol/mol / RP 0.76 nmol/mol NO_2 duct - NH_3 System 1: ZP 0.00 nmol/mol / RP 1.09 nmol/mol System 2: ZP -0.16 nmol/mol / RP 0.98 nmol/mol	yes	126
8.4.12 Averaging effect	≤ 7.0% of the measured value	E_{av} System 1: 3.1% NO E_{av} System 2: -2.9% NO E_{av} System 1: 0.7% NO2 E_{av} System 2: 3.2% NO_2	yes	130
8.4.13 Difference sample/calibration port	≤ 1.0%	Δ_{SC} System 1: 0.14% NO Δ_{SC} System 2: 0.06% NO Δ_{SC} System 1: -0.14% NO_2 Δ_{SC} System 2: -0.33% NO_2	yes	134
8.4.3 Response time (rise)	≤ 180 s	t_r System 1: 24 s (NO) t_r System 2: 25 s (NO) t_r System 1: 24 s (NO_2) t_r System 2: 25 s (NO_2)	yes	90
8.4.3 Response time (fall)	≤ 180 s	t_f System 1: 22 s (NO) t_f System 2: 23 s (NO) t_f System 1: 22 s (NO_2) t_f System 2: 22 s (NO_2)	yes	90

Performance characteristic	Performance criterion	Test result	Satisfied	Page
8.4.3 Difference between the rise and fall response time	≤ 10 s	t_d System 1: 2 s (NO) t_d System 2: 2 s (NO) t_d System 1: 2 s (NO_2) t_d System 2: 3 s (NO_2)	yes	90
8.4.14 Converter efficiency	≥ 98%	E_{conv} System 1: 99.6% E_{conv} System 2: 99.8%	yes	136
8.4.15 Residence time	≤ 3.0 s	System 1: 1.9 s System 2: 1.9 s	yes	139
8.5.7 Availability of the measuring system	> 90%	A_a System 1: 100% A_a System 2: 100%	yes	150
8.5.5 Reproducibility standard deviation under field conditions	≤ 5.0% of the average over a period of 3 months	$S_{r,f}$ System 1: 3.67% NO_2 $S_{r,f}$ System 2: 3.67% NO_2	yes	145
8.5.4 Long-term drift at zero point	≤ 5.0 nmol/mol	$C_{,z}$ System 1: -0.92 nmol/mol NO $C_{,z}$ System 2: 1.08 nmol/mol NO $C_{,z}$ System 1: 0.75 nmol/mol NO_2 $C_{,z}$ System 2: 0.87 nmol/mol NO_2	yes	140
8.5.4 Long-term drift at span	≤ 5.0% of the upper limit of the certification range	$C_{,s}$ System 1: max. 0.93% NO $C_{,s}$ System 2: max. 1.02% NO $C_{,s}$ System 1: max. 2.29% NO_2 $C_{,s}$ System 2: max. 2.05% NO_2	yes	140
8.4.4 Short-term drift at zero	≤ 2.0 nmol/mol over 12 h	$D_{s,z}$ System 1: 0.06 nmol/mol (NO) $D_{s,z}$ System 2: -0.27 nmol/mol (NO) $D_{s,z}$ System 1: -0.03 nmol/mol (NO_2) $D_{s,z}$ System 2: -0.26 nmol/mol (NO_2)	yes	95
8.4.4 Short-term drift at span	≤ 6.0 nmol/mol over 12 h	$D_{s,s}$ System 1: 2.36 nmol/mol (NO) $D_{s,s}$ System 2: 1.11 nmol/mol (NO) $D_{s,s}$ System 1: 2.76 nmol/mol (NO_2) $D_{s,s}$ System 2: 2.72 nmol/mol (NO_2)	yes	95

Table 75: Expanded uncertainty, laboratory test for NO, system 1

Measuring device:	N500	Serial-No.:	65		
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	0.130	$u_{r,z}$	0.02	0.0004	
2	Repeatability standard deviation at 1h-limit value	≤	3.0 nmol/mol	1.630	$u_{r,lh}$	0.05	0.0029	
3	"lack of fit" at 1h-limit value	≤	4.0% of measured value	1.720	$u_{l,lh}$	1.04	1.0789	
4	Sensitivity coefficient of sample gas pressure at 1h-limit value	≤	8.0 nmol/mol/kPa	0.230	u_{gp}	0.58	0.3396	
5	Sensitivity coefficient of sample gas temperature at 1h-limit value	≤	3.0 nmol/mol/K	0.090	u_{gt}	0.23	0.0527	
6	Sensitivity coefficient of surrounding temperature at 1h-limit value	≤	3.0 nmol/mol/K	0.952	u_{st}	2.43	5.9012	
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)	0.000	u_{H2O}	0.06	0.0038	
		≤	10 nmol/mol (Span)	0.400				
8b	Interferent CO_2 with 500 µmol/mol	≤	5.0 nmol/mol (Zero)	0.400	$u_{int,pos}$	0.82	0.6667	
		≤	5.0 nmol/mol (Span)	1.800	or			
8c	Interferent NH_3 mit 200 nmol/mol	≤	5.0 nmol/mol (Zero)	0.600				
		≤	5.0 nmol/mol (Span)	1.200	$u_{int,neg}$			
9	Averaging effect	≤	7.0% of measured value	3.100	u_{av}	1.87	3.5048	
18	Difference sample/calibration port	≤	1.0%	0.140	$u_{\Delta sc}$	0.15	0.0214	
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	3.5842	nmol/mol
					Expanded uncertainty	U	7.1685	nmol/mol
					Relative expanded uncertainty	W	6.85	%
					Maximum allowed expanded uncertainty	W_{req}	15	%

Table 76: Expanded uncertainty, laboratory and field tests for NO, system 1

Measuring device:	N500	Serial-No.:	65		
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	0.130	$u_{r,z}$	0.02	0.0004	
2	Repeatability standard deviation at 1h-limit value	≤	3.0 nmol/mol	1.630	$u_{r,lh}$	not considered, as √2*ur,lh = 0,07 < ur,f	-	
3	"lack of fit" at 1h-limit value	≤	4.0% of measured value	1.720	$u_{l,lh}$	1.04	1.0789	
4	Sensitivity coefficient of sample gas pressure at 1h-limit value	≤	8.0 nmol/mol/kPa	0.230	u_{gp}	0.58	0.3396	
5	Sensitivity coefficient of sample gas temperature at 1h-limit value	≤	3.0 nmol/mol/K	0.090	u_{gt}	0.23	0.0527	
6	Sensitivity coefficient of surrounding temperature at 1h-limit value	≤	3.0 nmol/mol/K	0.952	u_{st}	2.43	5.9012	
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)	0.000	u_{H2O}	0.06	0.0038	
		≤	10 nmol/mol (Span)	0.400				
8b	Interferent CO_2 with 500 µmol/mol	≤	5.0 nmol/mol (Zero)	0.400	$u_{int,pos}$	0.82	0.6667	
		≤	5.0 nmol/mol (Span)	1.800	or			
8c	Interferent NH_3 mit 200 nmol/mol	≤	5.0 nmol/mol (Zero)	0.600				
		≤	5.0 nmol/mol (Span)	1.200	$u_{int,neg}$			
9	Averaging effect	≤	7.0% of measured value	3.100	u_{av}	1.87	3.5048	
10	Reproducibility standard deviation under field conditions	≤	5.0% of average over 3 months	3.670	$u_{r,f}$	3.84	14.7365	
11	Long term drift at zero level	≤	5.0 nmol/mol	-0.920	$u_{d,l,z}$	-0.53	0.2821	
12	Long term drift at span level	≤	5.0% of max. of certification range	0.930	$u_{d,l,lh}$	0.56	0.3154	
18	Difference sample/calibration port	≤	1.0%	0.140	$u_{\Delta sc}$	0.15	0.0214	
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	5.3080	nmol/mol
					Expanded uncertainty	U	10.6160	nmol/mol
					Relative expanded uncertainty	W	10.15	%
					Maximum allowed expanded uncertainty	W_{req}	15	%

Table 77: Expanded uncertainty, laboratory test for NO, system 2

Measuring device:	N500				Serial-No.:		76	
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	0.130	$u_{r,z}$	0.02	0.0005	
2	Repeatability standard deviation at 1h-limit value	≤	3.0 nmol/mol	1.340	$u_{r,lh}$	0.05	0.0021	
3	"lack of fit" at 1h-limit value	≤	4.0% of measured value	2.240	$u_{l,lh}$	1.35	1.8299	
4	Sensitivity coefficient of sample gas pressure at 1h-limit value	≤	8.0 nmol/mol/kPa	0.170	u_{gp}	0.43	0.1856	
5	Sensitivity coefficient of sample gas temperature at 1h-limit value	≤	3.0 nmol/mol/K	0.110	u_{gt}	0.28	0.0788	
6	Sensitivity coefficient of surrounding temperature at 1h-limit value	≤	3.0 nmol/mol/K	0.451	u_{st}	1.15	1.3244	
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)	-0.600	u_{H2O}	-0.11	0.0116	
		≤	10 nmol/mol (Span)	1.600				
8b	Interferent CO_2 with 500 µmol/mol	≤	5.0 nmol/mol (Zero)	0.400	$u_{int,pos}$	0.90	0.8171	
		≤	5.0 nmol/mol (Span)	0.800	or			
8c	Interferent NH_3 mit 200 nmol/mol	≤	5.0 nmol/mol (Zero)	1.000				
		≤	5.0 nmol/mol (Span)	1.400	$u_{int,neg}$			
9	Averaging effect	≤	7.0% of measured value	-2.900	u_{av}	-1.75	3.0672	
18	Difference sample/calibration port	≤	1.0%	0.060	$u_{\Delta sc}$	0.06	0.0039	
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		2.9089	nmol/mol
			Expanded uncertainty		U		5.8177	nmol/mol
			Relative expanded uncertainty		W		5.56	%
			Maximum allowed expanded uncertainty		W_{req}		15	%

Table 78: Expanded uncertainty, laboratory and field tests for NO, system 2

Measuring device:	N500				Serial-No.:		76	
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	0.130	$u_{r,z}$	0.02	0.0005	
2	Repeatability standard deviation at 1h-limit value	≤	3.0 nmol/mol	1.340	$u_{r,lh}$	not considered, as √2*ur,lh = 0,06 < ur,f	-	
3	"lack of fit" at 1h-limit value	≤	4.0% of measured value	2.240	$u_{l,lh}$	1.35	1.8299	
4	Sensitivity coefficient of sample gas pressure at 1h-limit value	≤	8.0 nmol/mol/kPa	0.170	u_{gp}	0.43	0.1856	
5	Sensitivity coefficient of sample gas temperature at 1h-limit value	≤	3.0 nmol/mol/K	0.110	u_{gt}	0.28	0.0788	
6	Sensitivity coefficient of surrounding temperature at 1h-limit value	≤	3.0 nmol/mol/K	0.451	u_{st}	1.15	1.3244	
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)	-0.600	u_{H2O}	-0.11	0.0116	
		≤	10 nmol/mol (Span)	1.600				
8b	Interferent CO_2 with 500 µmol/mol	≤	5.0 nmol/mol (Zero)	0.400	$u_{int,pos}$	0.90	0.8171	
		≤	5.0 nmol/mol (Span)	0.800	or			
8c	Interferent NH_3 mit 200 nmol/mol	≤	5.0 nmol/mol (Zero)	1.000				
		≤	5.0 nmol/mol (Span)	1.400	$u_{int,neg}$			
9	Averaging effect	≤	7.0% of measured value	-2.900	u_{av}	-1.75	3.0672	
10	Reproducibility standard deviation under field conditions	≤	5.0% of average over 3 months	3.670	$u_{r,f}$	3.84	14.7365	
11	Long term drift at zero level	≤	5.0 nmol/mol	1.080	$u_{d,l,z}$	0.62	0.3888	
12	Long term drift at span level	≤	5.0% of max. of certification range	1.020	$u_{d,l,lh}$	0.62	0.3794	
18	Difference sample/calibration port	≤	1.0%	0.060	$u_{\Delta sc}$	0.06	0.0039	
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		4.8951	nmol/mol
			Expanded uncertainty		U		9.7902	nmol/mol
			Relative expanded uncertainty		W		9.36	%
			Maximum allowed expanded uncertainty		W_{req}		15	%

Table 79: Expanded uncertainty, laboratory test for NO_2, system 1

Measuring device:	N500				Serial-No.:		65	
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	0.000	$u_{r,z}$	0.00	0.0000	
2	Repeatability standard deviation at 1h-limit value	≤	3.0 nmol/mol	0.080	$u_{r,lh}$	0.01	0.0002	
3	"lack of fit" at 1h-limit value	≤	4.0% of measured value	0.850	$u_{l,lh}$	0.51	0.2635	
4	Sensitivity coefficient of sample gas pressure at 1h-limit value	≤	8.0 nmol/mol/kPa	0.100	u_{gp}	0.91	0.8206	
5	Sensitivity coefficient of sample gas temperature at 1h-limit value	≤	3.0 nmol/mol/K	0.010	u_{gt}	0.09	0.0082	
6	Sensitivity coefficient of surrounding temperature at 1h-limit value	≤	3.0 nmol/mol/K	0.231	u_{st}	2.09	4.3787	
7	Sensitivity coefficient of electrical voltage at 1h-limit value	≤	0.30 nmol/mol/V	0.020	u_V	0.27	0.0727	
8a	Interferent H_20 with 19 mmol/mol	≤	10 nmol/mol (Zero)	0.270	u_{H2O}	0.25	0.0606	
		≤	10 nmol/mol (Span)	0.330				
8b	Interferent CO_2 with 500 µmol/mol	≤	5.0 nmol/mol (Zero)	0.000	$u_{int,pos}$	1.03	1.0599	
		≤	5.0 nmol/mol (Span)	0.700	or			
8c	Interferent NH_3 mit 200 nmol/mol	≤	5.0 nmol/mol (Zero)	0.000				
		≤	5.0 nmol/mol (Span)	1.090	$u_{int,neg}$			
9	Averaging effect	≤	7.0% of measured value	0.700	u_{av}	0.42	0.1787	
18	Difference sample/calibration port	≤	1.0%	-0.140	$u_{\Delta sc}$	-0.15	0.0214	
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		2.8520	nmol/mol
				Expanded uncertainty	U		5.7040	nmol/mol
				Relative expanded uncertainty	W		5.45	%
				Maximum allowed expanded uncertainty	W_{req}		15	%

Table 80: Expanded uncertainty, laboratory and field tests for NO_2, system 1

Measuring device:	N500				Serial-No.:		65	
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	0.000	$u_{r,z}$	0.00	0.0000	
2	Repeatability standard deviation at 1h-limit value	≤	3.0 nmol/mol	0.080	$u_{r,lh}$	not considered, as √2*ur,lh = 0,01 < ur,f	-	
3	"lack of fit" at 1h-limit value	≤	4.0% of measured value	0.850	$u_{l,lh}$	0.51	0.2635	
4	Sensitivity coefficient of sample gas pressure at 1h-limit value	≤	8.0 nmol/mol/kPa	0.100	u_{gp}	0.91	0.8206	
5	Sensitivity coefficient of sample gas temperature at 1h-limit value	≤	3.0 nmol/mol/K	0.010	u_{gt}	0.09	0.0082	
6	Sensitivity coefficient of surrounding temperature at 1h-limit value	≤	3.0 nmol/mol/K	0.231	u_{st}	2.09	4.3787	
7	Sensitivity coefficient of electrical voltage at 1h-limit value	≤	0.30 nmol/mol/V	0.020	u_V	0.27	0.0727	
8a	Interferent H_20 with 19 mmol/mol	≤	10 nmol/mol (Zero)	0.270	u_{H2O}	0.25	0.0606	
		≤	10 nmol/mol (Span)	0.330				
8b	Interferent CO_2 with 500 µmol/mol	≤	5.0 nmol/mol (Zero)	0.000	$u_{int,pos}$	1.03	1.0599	
		≤	5.0 nmol/mol (Span)	0.700	or			
8c	Interferent NH_3 mit 200 nmol/mol	≤	5.0 nmol/mol (Zero)	0.000				
		≤	5.0 nmol/mol (Span)	1.090	$u_{int,neg}$			
9	Averaging effect	≤	7.0% of measured value	0.700	u_{av}	0.42	0.1787	
10	Reproducibility standard deviation under field conditions	≤	5.0% of average over 3 months	3.670	$u_{r,f}$	3.84	14.7365	
11	Long term drift at zero level	≤	5.0 nmol/mol	0.750	$u_{d,l,z}$	0.43	0.1875	
12	Long term drift at span level	≤	5.0% of max. of certification range	2.290	$u_{d,l,lh}$	1.38	1.9126	
18	Difference sample/calibration port	≤	1.0%	-0.140	$u_{\Delta sc}$	-0.15	0.0214	
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		4.9970	nmol/mol
				Expanded uncertainty	U		9.9940	nmol/mol
				Relative expanded uncertainty	W		9.55	%
				Maximum allowed expanded uncertainty	W_{req}		15	%

Table 81: Expanded uncertainty, laboratory test for NO_2, system 2

Measuring device:	N500			Serial-No.:	76	
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	0.110	$u_{r,z}$	0.02	0.0003
2	Repeatability standard deviation at 1h-limit value	≤	3.0 nmol/mol	0.080	$u_{r,lh}$	0.01	0.0002
3	"lack of fit" at 1h-limit value	≤	4.0% of measured value	0.720	$u_{l,lh}$	0.43	0.1891
4	Sensitivity coefficient of sample gas pressure at 1h-limit value	≤	8.0 nmol/mol/kPa	0.080	u_{gp}	0.72	0.5252
5	Sensitivity coefficient of sample gas temperature at 1h-limit value	≤	3.0 nmol/mol/K	0.010	u_{gt}	0.09	0.0082
6	Sensitivity coefficient of surrounding temperature at 1h-limit value	≤	3.0 nmol/mol/K	0.241	u_{st}	2.18	4.7661
7	Sensitivity coefficient of electrical voltage at 1h-limit value	≤	0.30 nmol/mol/V	0.010	u_V	0.13	0.0182
8a	Interferent H_20 with 19 mmol/mol	≤	10 nmol/mol (Zero)	0.000	u_{H2O}	0.16	0.0267
		≤	10 nmol/mol (Span)	0.220			
8b	Interferent CO_2 with 500 µmol/mol	≤	5.0 nmol/mol (Zero)	-0.210	$u_{int,pos}$ or $u_{int,neg}$	1.00	0.9999
		≤	5.0 nmol/mol (Span)	0.760			
8c	Interferent NH_3 mit 200 nmol/mol	≤	5.0 nmol/mol (Zero)	-0.160			
		≤	5.0 nmol/mol (Span)	0.980			
9	Averaging effect	≤	7.0% of measured value	3.200	u_{av}	1.93	3.7346
18	Difference sample/calibration port	≤	1.0%	-0.330	$u_{\Delta sc}$	-0.35	0.1191
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	3.3950	nmol/mol
Expanded uncertainty	U	6.7900	nmol/mol
Relative expanded uncertainty	W	6.49	%
Maximum allowed expanded uncertainty	W_{req}	15	%

Table 82: Expanded uncertainty, laboratory and field tests for NO_2, system 2

Measuring device:	N500			Serial-No.:	76	
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	0.110	$u_{r,z}$	0.02	0.0003
2	Repeatability standard deviation at 1h-limit value	≤	3.0 nmol/mol	0.080	$u_{r,lh}$	not considered, as √2*ur,lh = 0,01 < ur,f	-
3	"lack of fit" at 1h-limit value	≤	4.0% of measured value	0.720	$u_{l,lh}$	0.43	0.1891
4	Sensitivity coefficient of sample gas pressure at 1h-limit value	≤	8.0 nmol/mol/kPa	0.080	u_{gp}	0.72	0.5252
5	Sensitivity coefficient of sample gas temperature at 1h-limit value	≤	3.0 nmol/mol/K	0.010	u_{gt}	0.09	0.0082
6	Sensitivity coefficient of surrounding temperature at 1h-limit value	≤	3.0 nmol/mol/K	0.241	u_{st}	2.18	4.7661
7	Sensitivity coefficient of electrical voltage at 1h-limit value	≤	0.30 nmol/mol/V	0.010	u_V	0.13	0.0182
8a	Interferent H_20 with 19 mmol/mol	≤	10 nmol/mol (Zero)	0.000	u_{H2O}	0.16	0.0267
		≤	10 nmol/mol (Span)	0.220			
8b	Interferent CO_2 with 500 µmol/mol	≤	5.0 nmol/mol (Zero)	-0.210	$u_{int,pos}$ or $u_{int,neg}$	1.00	0.9999
		≤	5.0 nmol/mol (Span)	0.760			
8c	Interferent NH_3 mit 200 nmol/mol	≤	5.0 nmol/mol (Zero)	-0.160			
		≤	5.0 nmol/mol (Span)	0.980			
9	Averaging effect	≤	7.0% of measured value	3.200	u_{av}	1.93	3.7346
10	Reproducibility standard deviation under field conditions	≤	5.0% of average over 3 months	3.670	$u_{r,f}$	3.84	14.7365
11	Long term drift at zero level	≤	5.0 nmol/mol	0.870	$u_{d,l,z}$	0.50	0.2523
12	Long term drift at span level	≤	5.0% of max. of certification range	2.050	$u_{d,l,lh}$	1.24	1.5327
18	Difference sample/calibration port	≤	1.0%	-0.330	$u_{\Delta sc}$	-0.35	0.1191
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	5.2959	nmol/mol
Expanded uncertainty	U	10.5919	nmol/mol
Relative expanded uncertainty	W	10.13	%
Maximum allowed expanded uncertainty	W_{req}	15	%

8. Recommendations for use in practice

Work in the maintenance interval

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

- Visual inspections/telemetric inspections on a regular basis
- Checking the status of the system
- No error messages
- Performing zero and span 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

Dipl.-Ing. Martin Schneider	Dipl.-Ing. Guido Baum

Cologne, 30 July 2021
936/21251100/A

9. 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] Guide, Demonstration of Equivalence of Ambient Air Monitoring Methods, English version dated January 2010

Annexes

Annex 1:

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

The field test which was carried out according to VDI 4202-1 and EN 14211 was carried out from 09 November 2020 to 15 February 2021.

However, the entire field setup was installed from November 2020 until the end of June 2021. During the entire period, a performance-tested CLD reference analyser of the type Horiba APNA 370 (SN 43286610022) was running in parallel to the N500 systems. This reference analyser was connected to the same sampling mast as the two test instruments. The length of the test gas line to the analyser was approx. 2 m.

With this system, additional tests were carried out according to the guide Demonstration of Equivalence of Ambient Air Monitoring Methods.

To this effect, four measurement periods, each lasting one month, were selected over a period of six months to compare the N500 systems with an already performance-tested SRM system. The measurement periods were selected in such a way that different environmental conditions (temperature, humidity, ambient pressure, NO_2 concentration) could be included in the evaluation of the measuring system. Therefore, the months of December 2020, January 2021, May 2021 and June 2021 were evaluated in accordance with the guide Demonstration of Equivalence of Ambient Air Monitoring Methods.

Before the start of each evaluated period, the adjustment of the test instruments and the reference system was checked. In the case of the Horiba APNA 370 reference analyser, the converter efficiency was also regularly checked and remained at > 98 % throughout the entire test.

The assessment was carried out separately for NO and NO_2.

7.1 Determination of relative uncertainty between test instruments W_{bs} [8.5.3.2]

The relative uncertainty between the test items W_{bs} shall be determined in accordance with point 8.5.3.2 of the guidance document "Demonstration of Equivalence of Ambient Air Monitoring Methods".

7.2 Equipment

Not required for this performance criterion.

7.3 Testing

The test was conducted in the field test in four different months (December, January, May and June) at the field test site in Cologne. Different seasons and different test gas concentrations were taken into account.

7.4 Evaluation

According to point 8.5.3.2 of the Demonstration of Equivalence of Ambient Air Monitoring Methods guide:

The uncertainty between the test items W_{bs} must be ≤ 5 %. As no other reference value is given, the 1 hour limit value for NO_2 (200 µg/m³ = 104.6 ppb) (2008/50/EC) was used as the reference value. Thus, the maximum uncertainty between the test items may be a maximum of 5.2 ppb for NO_2.

For the component NO, the c_t value for NO (631.3 µg/m³ = 505 pbb) was used as a criterion. This means that the maximum uncertainty between the test items for NO must not exceed 25 ppb.

An uncertainty above 5.2 ppb or 25 ppb between the two test items is an indication that the performance of one or both systems is inadequate and equivalence cannot be explained.

The uncertainty between the test items is determined individually for each test month.

The uncertainty between the test items W_{bs} is calculated from the differences of all 1 hour mean values of the test specimens operated in parallel according to the following equation:

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

Where: $y_{i,1}$ and $y_{i,2}$ = Results of the parallel measurements of individual 1h-values i
y = Average of the test item readings
n = Number of 1h values

7.5 Assessment

The uncertainty between the test items W_{bs} remained below the required maximum values with a maximum of 1.440 ppb for NO and 1.846 ppb for NO_2.

Criterion satisfied? yes

7.6 Detailed presentation of test results

Table 83 and Table 84 list the calculated values for the uncertainties W_{bs} between test items. Corresponding charts are provided in Figure 18 to Figure 25.

Table 83: Uncertainty between test systems (W_{bs}), NO

Tested instru-ments	**Measurement month**	**Number of measurements**	**Uncertainty W_{bs}**
Component NO			
SN 65 / SN 76	December	744	0.063
SN 65 / SN 76	January	744	0.003
SN 65 / SN 76	May	744	0.063
SN 65 / SN 76	June	720	0.063

Table 84: Uncertainty between test systems (W_{bs}), NO_2

Tested instru-ments	**Measurement month**	**Number of measurements**	**Uncertainty W_{bs}**
Component NO_2			
SN 65 / SN 76	December	744	0.022
SN 65 / SN 76	January	744	0.018
SN 65 / SN 76	May	744	0.021
SN 65 / SN 76	June	720	0.020

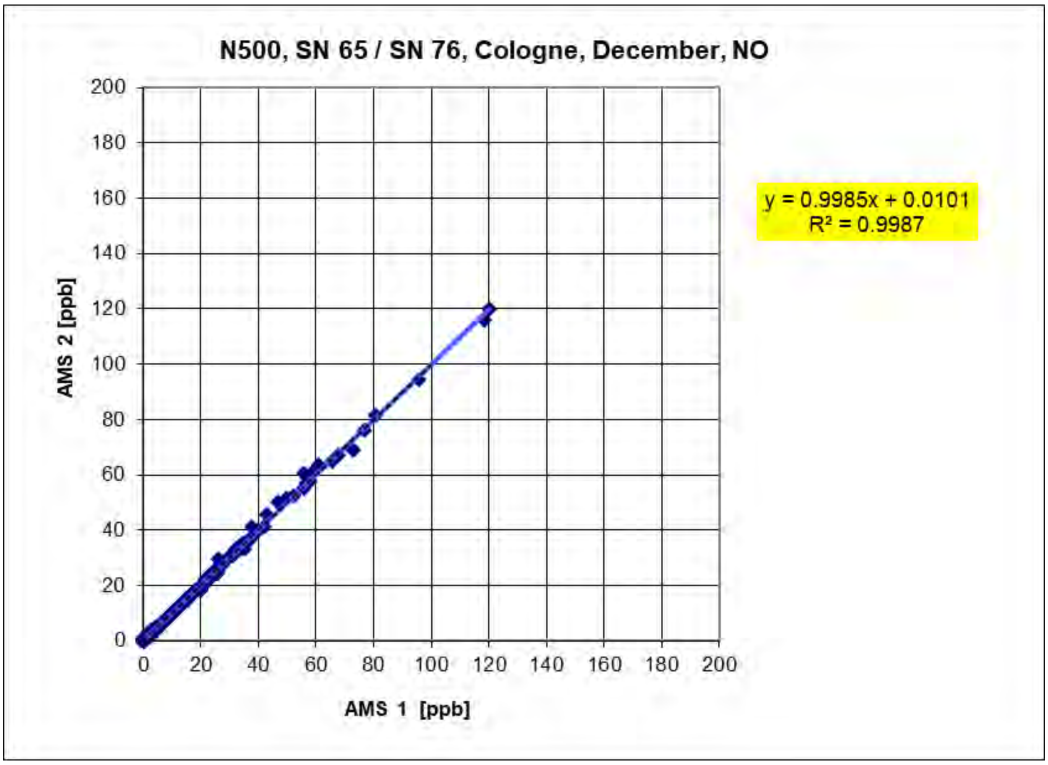


Figure 18: Parallel measurements with the test systems, December, NO

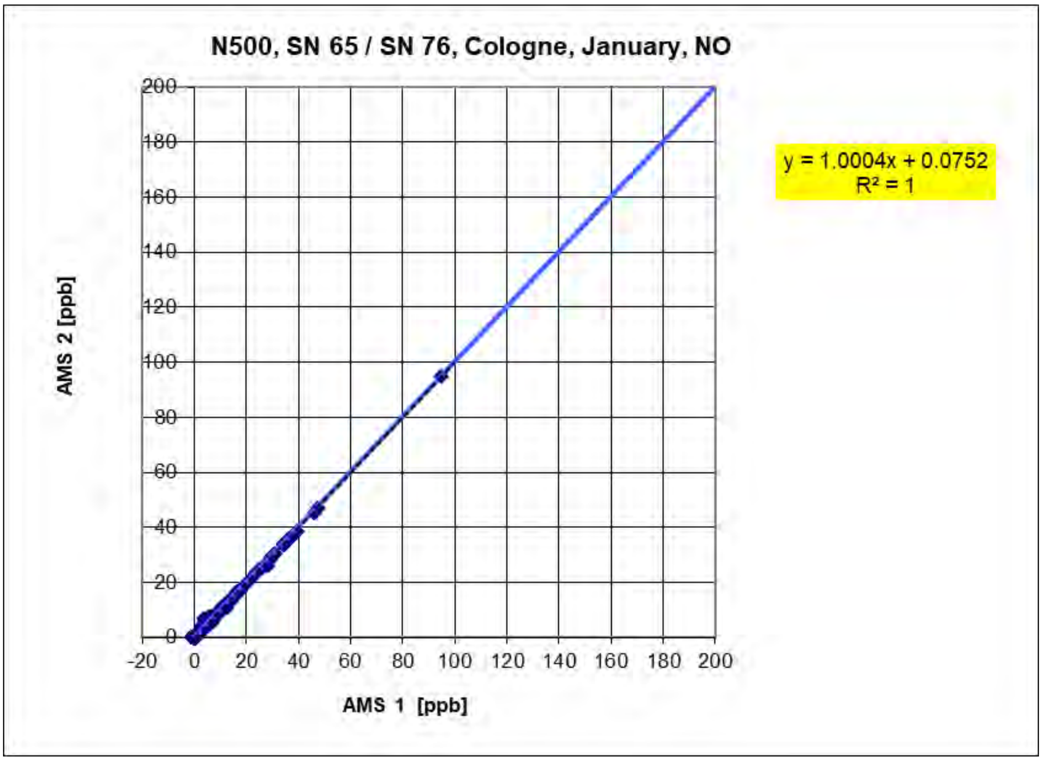


Figure 19: Parallel measurements with the test systems, January, NO

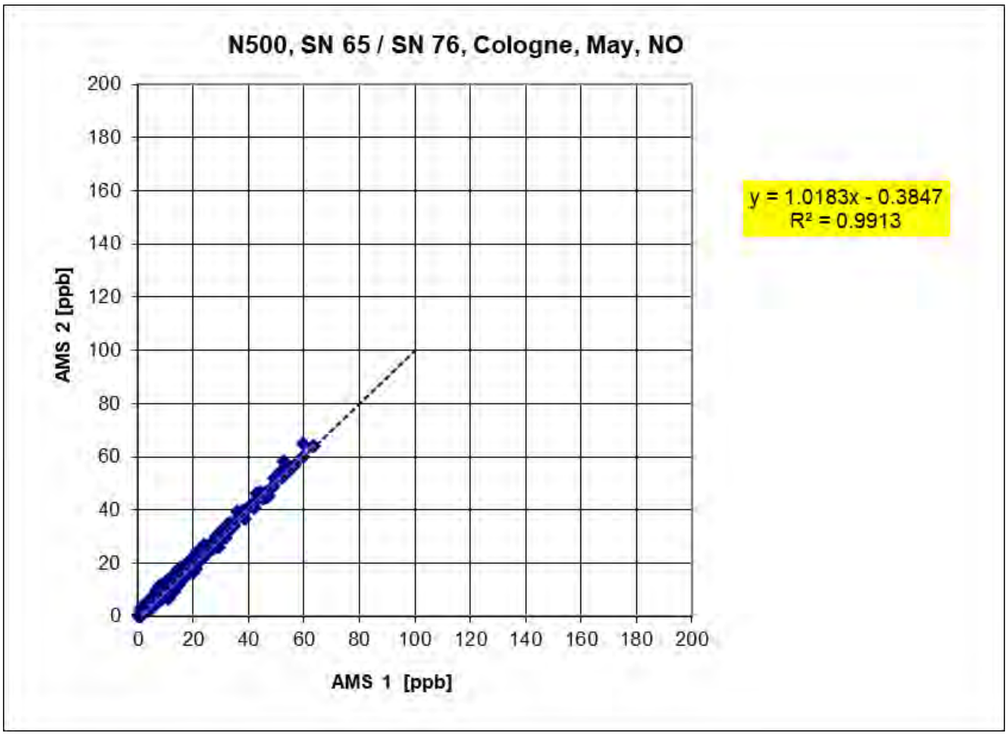


Figure 20: Parallel measurements with the test systems, May, NO

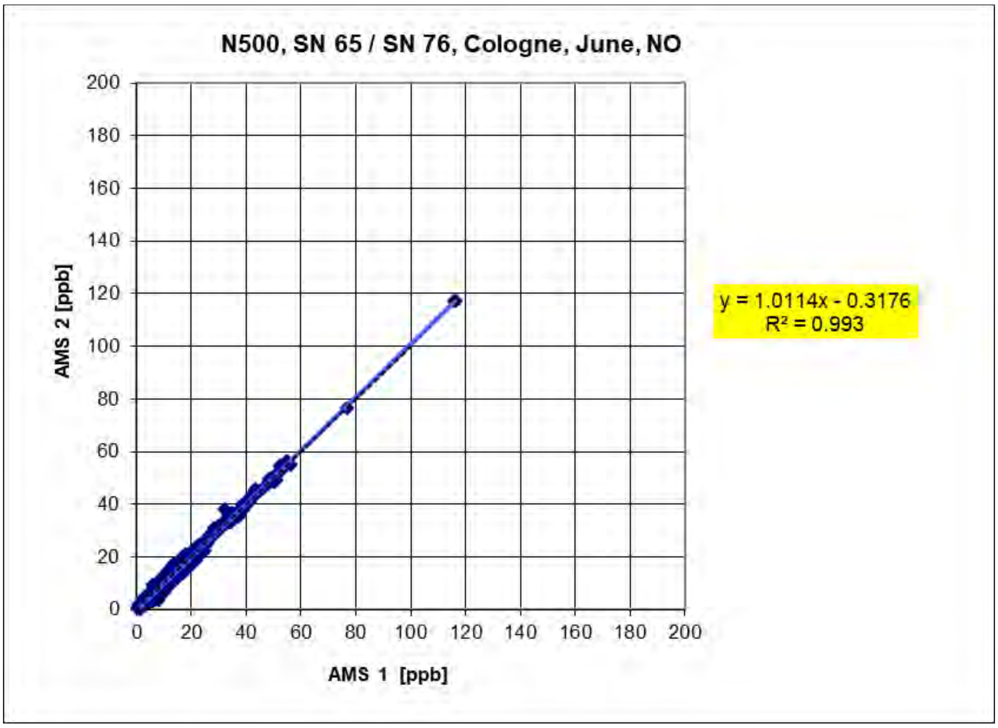


Figure 21: Parallel measurements with the test systems, June, NO

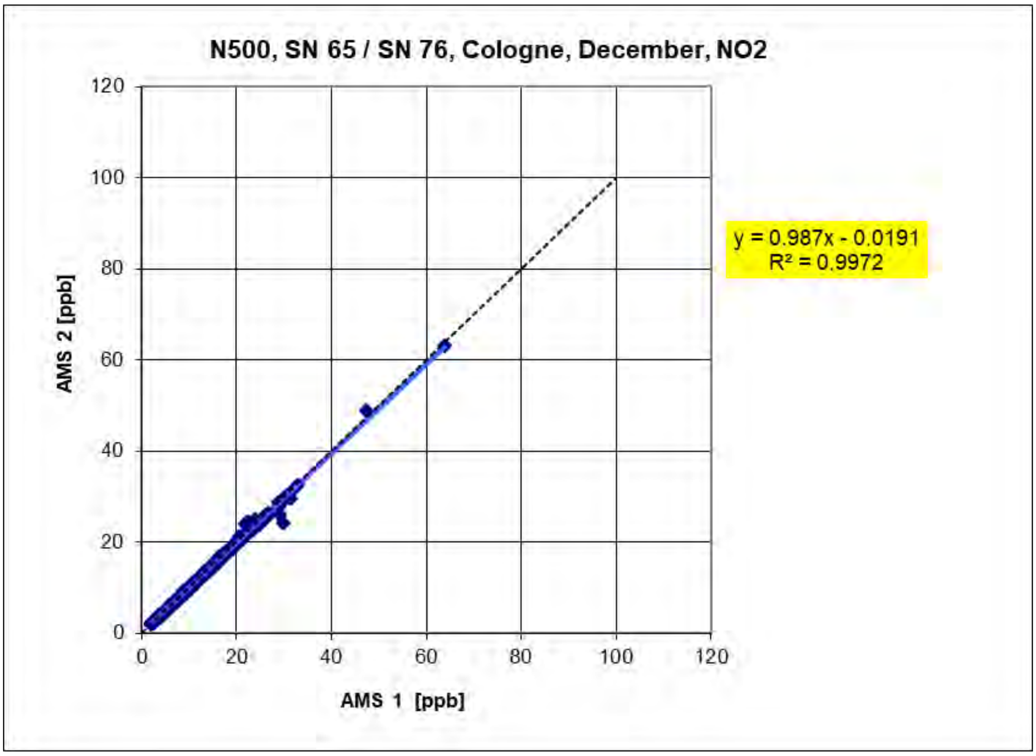


Figure 22: Parallel measurements with the test systems, December, NO_2

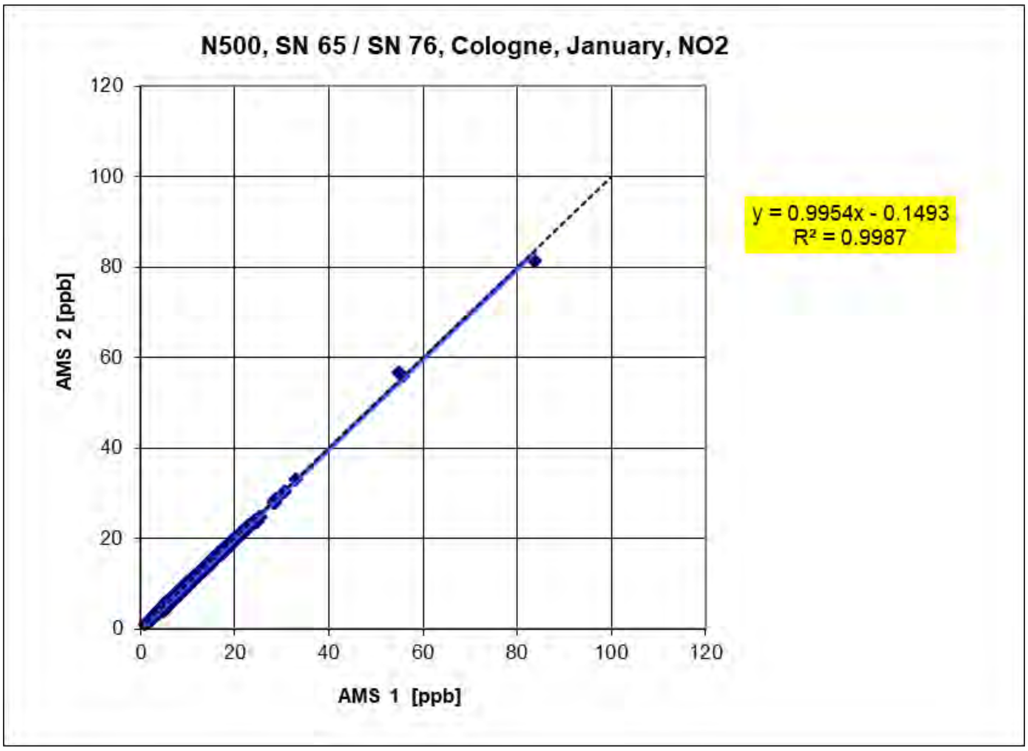


Figure 23: Parallel measurements with the test systems, January, NO_2

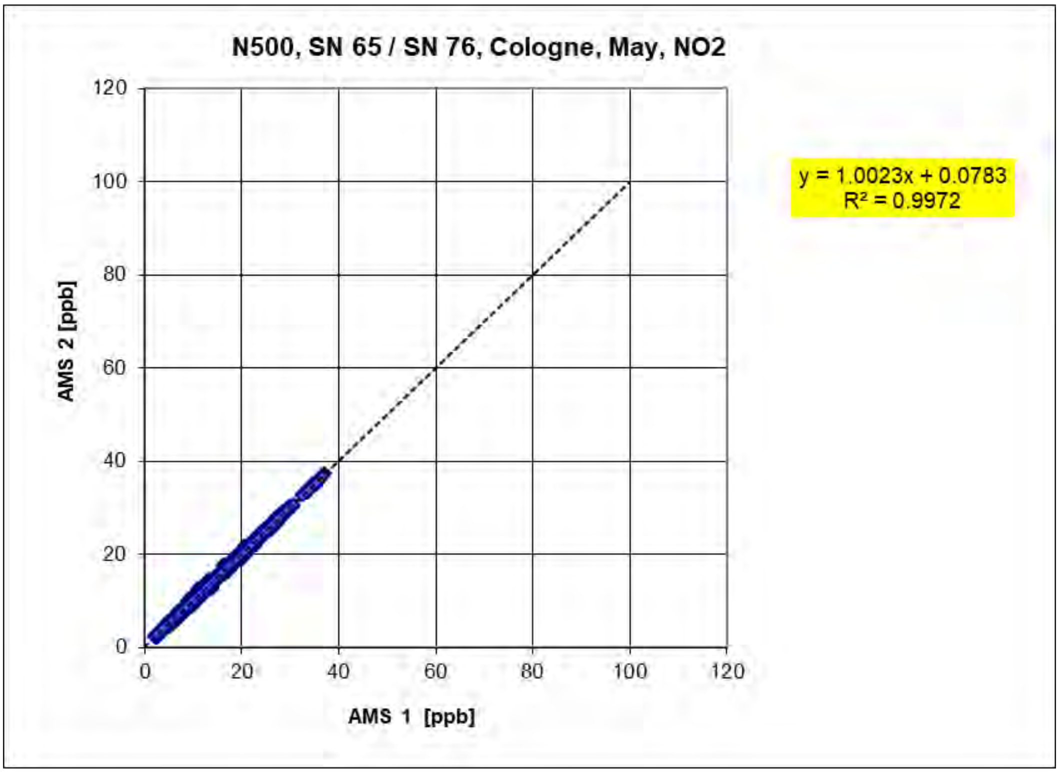


Figure 24: Parallel measurements with the test systems, May, NO_2

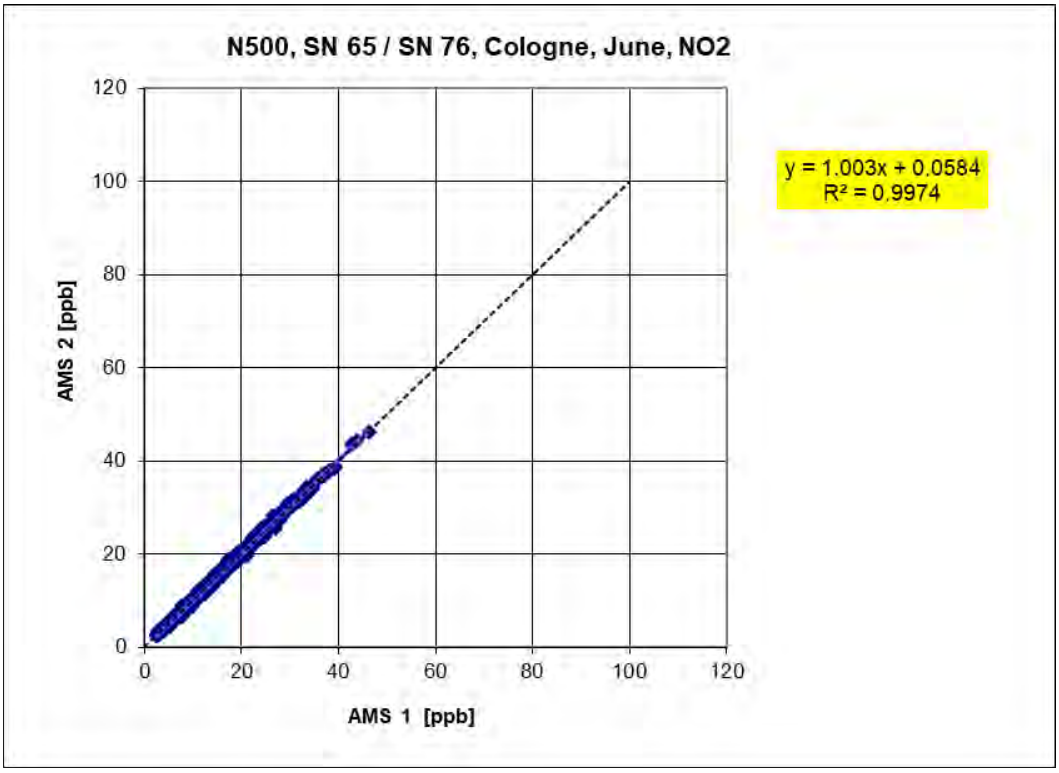


Figure 25: Parallel measurements with the test systems, June, NO_2

7.1 Comparison with the standard reference method [8.5.3.3]

The equivalence of the test items to the reference method shall be demonstrated in accordance with point 8.5.3.3 of the Demonstration of Equivalence of Ambient Air Monitoring Methods guide. The highest calculated expanded uncertainty of the test items is to be compared with the requirements for the data quality objectives according to 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 test was conducted in the field test in four different months (December, January, May and June) at the field test site in Cologne. Different seasons and different test gas concentrations were taken into account.

Four measurements were carried out, each lasting one month. The measurements were spread over half a year. 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 correlation between the mean values of the reference instruments and the test instruments is established by means of orthogonal regression.

For analysis, the result uncertainty w_{c_s} of the test samples from the comparison with the reference method is described according to the following equation, which describes w_{c_s} as a function of the sample gas concentration xi.

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

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

u(xi) = is the random uncertainty 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:

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

[Item 8.5.3] For all data sets, the combined uncertainty of the test items $w_{c,CM}$ is calculated by combining the contributions from 8.5.3.1 and 8.5.3.2 according to the following equation:

$$w^2_{c,CM}(y_i) = \frac{u^2_{c\_s}(y_i)}{y_i^2}$$

For each data set the uncertainty $w_{c,CM}$ at the 1 h limit value for NO_2 (here 200 µg/m³ = 104.6 ppb) is calculated, where y_i is used as the concentration at the limit value. For NO, the uncertainty is based on the 1 h limit value (631.3 µg/m³ = 505 ppb).

[point 8.5.3.4] For each data set, the expanded relative uncertainty of the results of the test items is calculated by multiplying $w_{c,CM}$ by a 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 evaluated with the data quality requirements for air quality measurements according to the EU Directive. The established expanded relative uncertainty W_{cm} was at 15% for NO and NO_2

7.5 Assessment

The determined uncertainties W_{CM} are below the defined expanded relative uncertainty W_{cm} of 15 % without applying correction factors for all data sets considered.

Criterion satisfied? yes

7.6 Detailed presentation of test results

In Table 85 and in Table 86 a summary presentation and evaluation of the expanded measurement uncertainties W_{CM} from the field test investigations are given.

Table 87 to Table 94 show the results of the evaluations of the individual data sets.

Table 85: Expanded measurement uncertainties W_{CM} from the field investigations for NO

Month	Component	Limit value ppb	Slope b (ppb)/(ppb)	Axis intercept a ppb	u_{c_s} at the limit value ppb	w_{CM} %	W_{CM} %	$W_{CM} \leq W_{dqo}$ (W_{dqo} = 15%)
December	NO	505	0.99	-0.43	6.59	1.30	2.61	yes
January	NO	505	1.00	-0.94	0.93	0.18	0.37	yes
May	NO	505	0.98	-0.71	9.33	1.85	3.69	yes
June	NO	505	0.97	-1.35	18.64	3.69	7.38	yes

Table 86: Expanded measurement uncertainties W_{CM} from the field investigations for NO_2

Month	Component	Limit value ppb	Slope b (ppb)/(ppb)	Axis intercept a ppb	u_{c_s} at the limit value ppb	w_{CM} %	W_{CM} %	$W_{CM} \leq W_{dqo}$ (W_{dqo} = 15%)
December	NO_2	104.6	1.00	0.00	0.25	0.29	0.57	yes
January	NO_2	104.6	1.00	-0.04	0.48	0.46	0.91	yes
May	NO_2	104.6	1.00	-1.63	1.47	1.41	2.81	yes
June	NO_2	104.6	1.00	-1.67	1.82	1.74	3.48	yes

Table 87: Comparison of the tested and reference instruments, December, NO

Comparison candidate with refernce according to guidance "Demonstration of Equivalence Of Ambient Air Monitoring Methods"				
Device	N500	SN	SN 65 / SN 76	
Testside / month	Cologne, December	Limit value	505	ppb
Component	NO	allowed uncertainty	15	%
Results of the regression analysis				
Slope b	**0.99**	**significant**		
Uncertainty of b	**0.00**			
Ordinate intercept a	**-0.43**	**significant**		
Uncertainty of a	**0.03**			
Results of the equivalence test				
Deviation at limit value	**-6.55**	**ppb**		
Uncertainty u_{c_s} at limit value	**6.59**	**ppb**		
Combined measurement uncertainty w_{CM}	**1.30**	**%**		
Expanded uncertainty W_{CM}	**2.61**	**%**		
Status equivalence test	**passed**			

Table 88: Comparison of the tested and reference instruments, January, NO

Comparison candidate with refernce according to guidance "Demonstration of Equivalence Of Ambient Air Monitoring Methods"				
Device	N500	SN	SN 65 / SN 76	
Testside / month	Cologne, January	Limit value	505	ppb
Component	NO	allowed uncertainty	15	%
Results of the regression analysis				
Slope b	**1.00**	**significant**		
Uncertainty of b	**0.00**			
Ordinate intercept a	**-0.94**	**significant**		
Uncertainty of a	**0.03**			
Results of the equivalence test				
Deviation at limit value	**0.54**	**ppb**		
Uncertainty u_{c_s} at limit value	**0.93**	**ppb**		
Combined measurement uncertainty w_{CM}	**0.18**	**%**		
Expanded uncertainty W_{CM}	**0.37**	**%**		
Status equivalence test	**passed**			

Table 89: Comparison of the tested and reference instruments, May, NO

Comparison candidate with refernce according to guidance "Demonstration of Equivalence Of Ambient Air Monitoring Methods"				
Device	N500	SN	SN 65 / SN 76	
Testside / month	Cologne, May	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	**-0.71**	**significant**		
Uncertainty of a	**0.05**			
Results of the equivalence test				
Deviation at limit value	**-9.28**	**ppb**		
Uncertainty u_{c_s} at limit value	**9.33**	**ppb**		
Combined measurement uncertainty w_{CM}	**1.85**	**%**		
Expanded uncertainty W_{CM}	**3.69**	**%**		
Status equivalence test	**passed**			

Table 90: Comparison of the tested and reference instruments, June, NO

Comparison candidate with refernce according to guidance "Demonstration of Equivalence Of Ambient Air Monitoring Methods"				
Device	N500	SN	SN 65 / SN 76	
Testside / month	Cologne, June	Limit value	505	ppb
Component	NO	allowed uncertainty	15	%
Results of the regression analysis				
Slope b	**0.97**	**significant**		
Uncertainty of b	**0.00**			
Ordinate intercept a	**-1.35**	**significant**		
Uncertainty of a	**0.06**			
Results of the equivalence test				
Deviation at limit value	**-18.61**	**ppb**		
Uncertainty u_{c_s} at limit value	**18.64**	**ppb**		
Combined measurement uncertainty w_{CM}	**3.69**	**%**		
Expanded uncertainty W_{CM}	**7.38**	**%**		
Status equivalence test	**passed**			

Table 91: Comparison of the tested and reference instruments, December, NO_2

Comparison candidate with refernce according to guidance "Demonstration of Equivalence Of Ambient Air Monitoring Methods"				
Device	N500	SN	SN 65 / SN 76	
Testside / month	Cologne, December	Limit value	104.6	ppb
Component	NO2	allowed uncertainty	15	%
Results of the regression analysis				
Slope b	**1.00**	**significant**		
Uncertainty of b	**0.00**			
Ordinate intercept a	**0.00**	**nicht significant**		
Uncertainty of a	**0.01**			
Results of the equivalence test				
Deviation at limit value	**0.25**	**ppb**		
Uncertainty u_{c_s} at limit value	**0.30**	**ppb**		
Combined measurement uncertainty w_{CM}	**0.29**	**%**		
Expanded uncertainty W_{CM}	**0.57**	**%**		
Status equivalence test	**passed**			

Table 92: Comparison of the tested and reference instruments, January, NO_2

Comparison candidate with refernce according to guidance "Demonstration of Equivalence Of Ambient Air Monitoring Methods"				
Device	N500	SN	SN 65 / SN 76	
Testside / month	Cologne, January	Limit value	104.6	ppb
Component	NO2	allowed uncertainty	15	%
Results of the regression analysis				
Slope b	**1.00**	**significant**		
Uncertainty of b	**0.00**			
Ordinate intercept a	**-0.04**	**significant**		
Uncertainty of a	**0.01**			
Results of the equivalence test				
Deviation at limit value	**0.46**	**ppb**		
Uncertainty u_{c_s} at limit value	**0.48**	**ppb**		
Combined measurement uncertainty w_{CM}	**0.46**	**%**		
Expanded uncertainty W_{CM}	**0.91**	**%**		
Status equivalence test	**passed**			

Table 93: Comparison of the tested and reference instruments, May, NO_2

Comparison candidate with refernce according to guidance "Demonstration of Equivalence Of Ambient Air Monitoring Methods"				
Device	N500	SN	SN 65 / SN 76	
Testside / month	Cologne, May	Limit value	104.6	ppb
Component	NO2	allowed uncertainty	15	%
Results of the regression analysis				
Slope b	**1.00**	**nicht significant**		
Uncertainty of b	**0.00**			
Ordinate intercept a	**-1.63**	**significant**		
Uncertainty of a	**0.05**			
Results of the equivalence test				
Deviation at limit value	**-1.37**	**ppb**		
Uncertainty u_{c_s} at limit value	**1.47**	**ppb**		
Combined measurement uncertainty w_{CM}	**1.41**	**%**		
Expanded uncertainty W_{CM}	**2.81**	**%**		
Status equivalence test	**passed**			

Table 94: Comparison of the tested and reference instruments, June, NO_2

Comparison candidate with refernce according to guidance "Demonstration of Equivalence Of Ambient Air Monitoring Methods"				
Device	N500	SN	SN 65 / SN 76	
Testside / month	Cologne, June	Limit value	104.6	ppb
Component	NO2	allowed uncertainty	15	%
Results of the regression analysis				
Slope b	**1.00**	**nicht significant**		
Uncertainty of b	**0.00**			
Ordinate intercept a	**-1.67**	**significant**		
Uncertainty of a	**0.06**			
Results of the equivalence test				
Deviation at limit value	**-1.70**	**ppb**		
Uncertainty u_{c_s} at limit value	**1.82**	**ppb**		
Combined measurement uncertainty w_{CM}	**1.74**	**%**		
Expanded uncertainty W_{CM}	**3.48**	**%**		
Status equivalence test	**passed**			

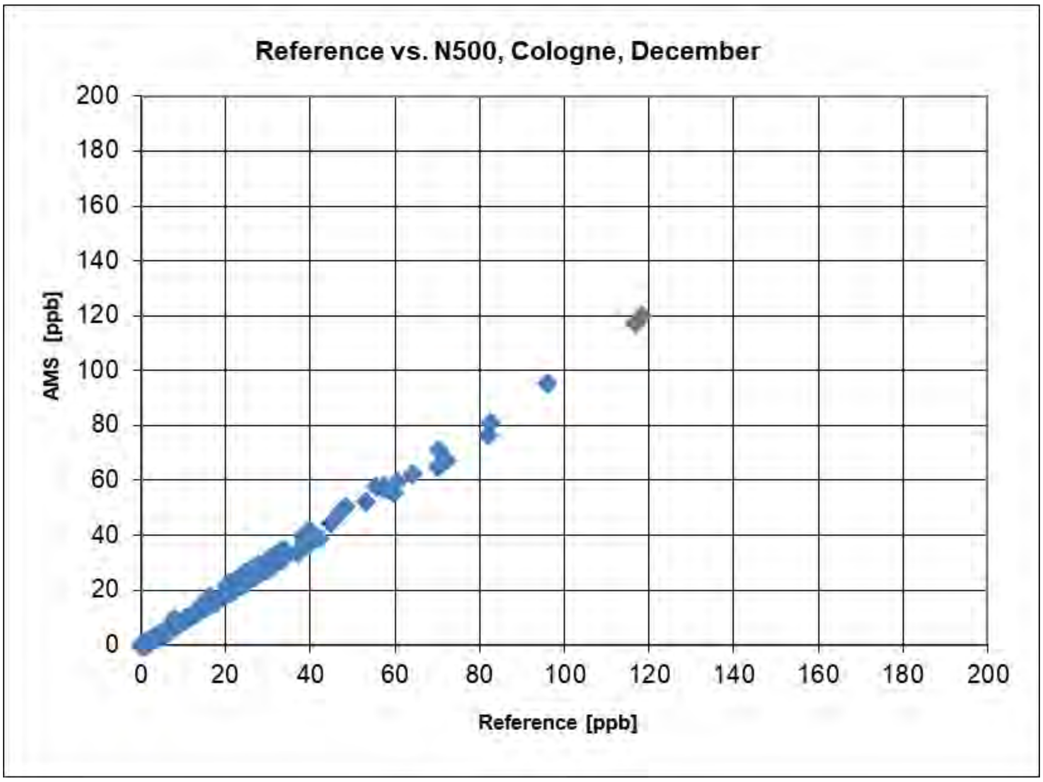


Figure 26: Reference vs. tested instrument, December, NO

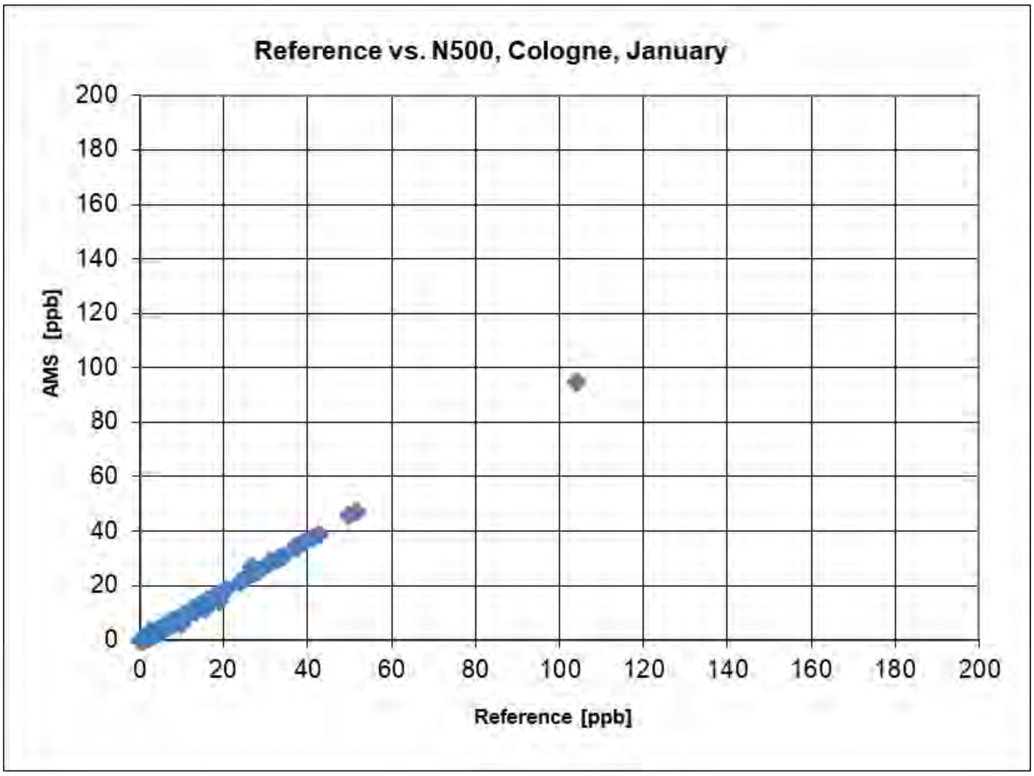


Figure 27: Reference vs. tested instrument, January, NO

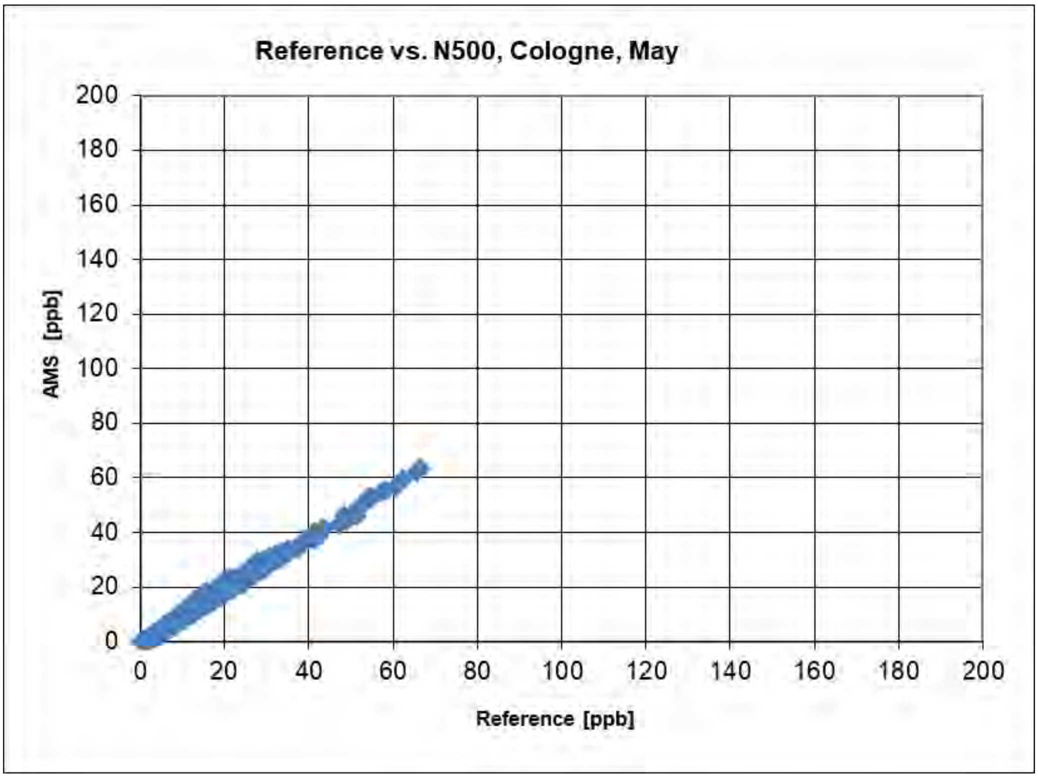


Figure 28: Reference vs. tested instrument, May, NO

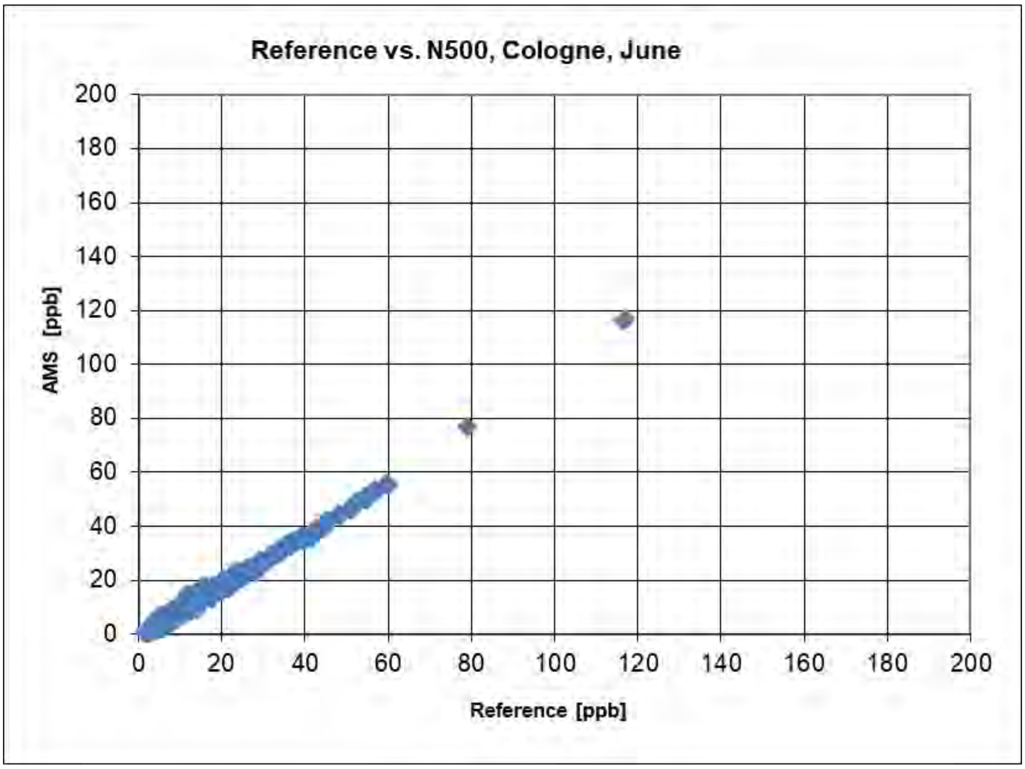


Figure 29: Reference vs. tested instrument, June, NO

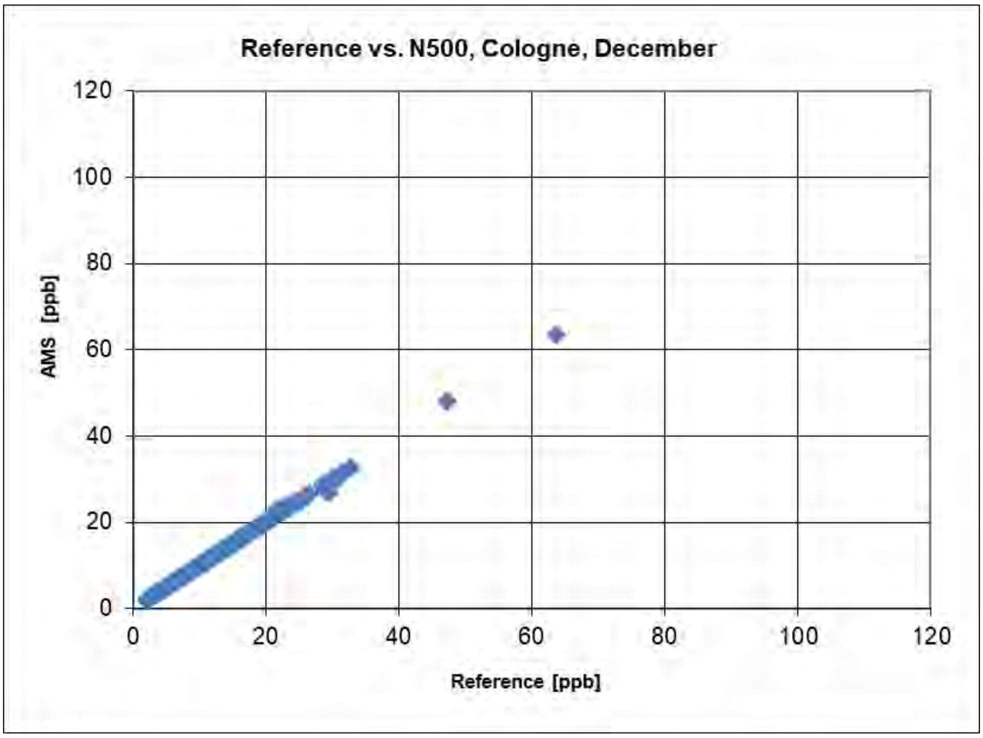


Figure 30: Reference vs. tested instrument, December, NO_2

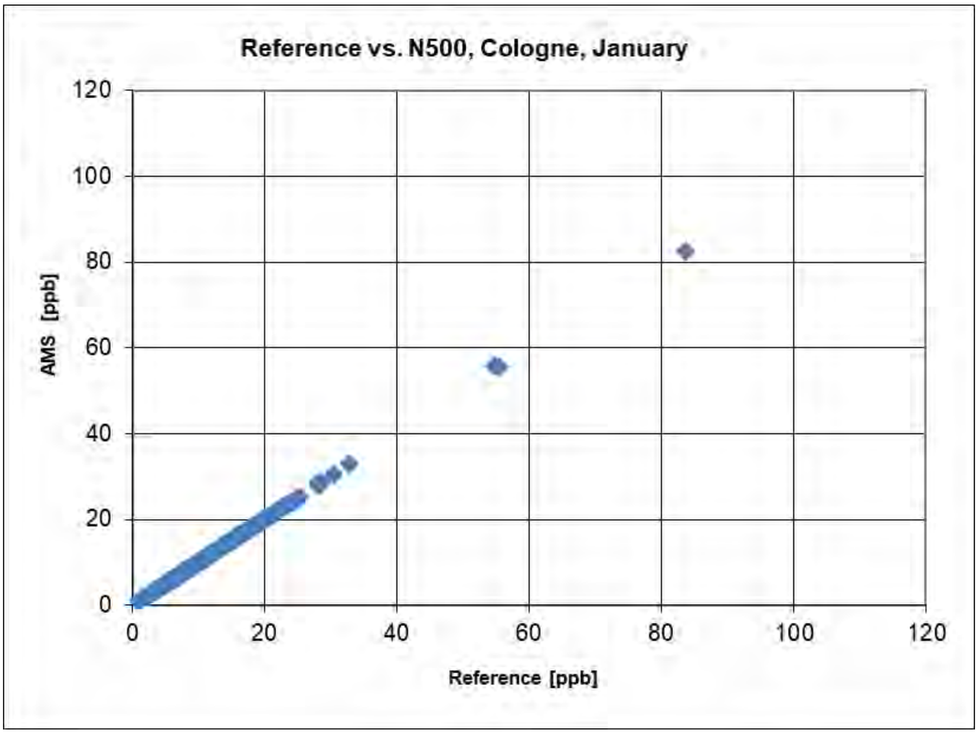


Figure 31: Reference vs. tested instrument, January, NO_2

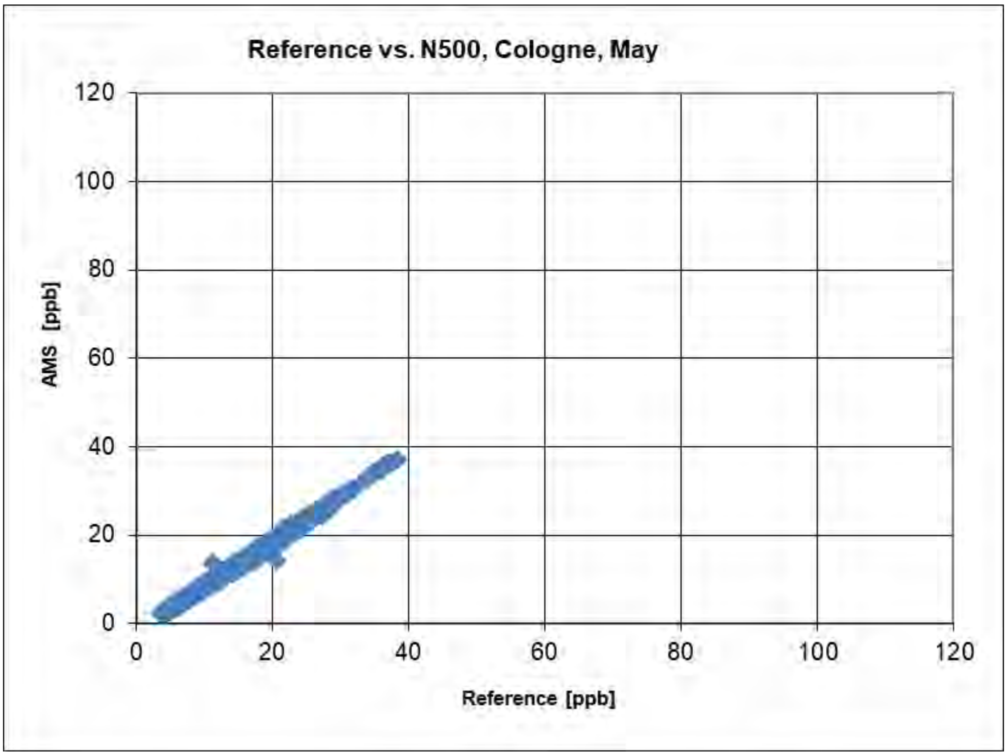


Figure 32: Reference vs. tested instrument, May, NO_2

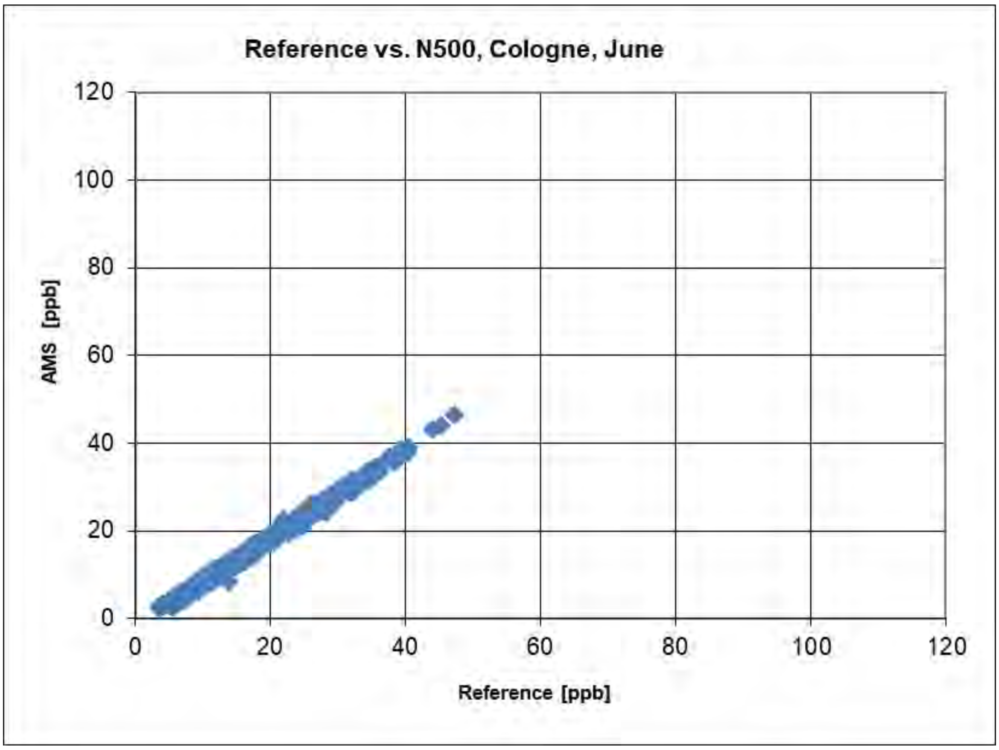


Figure 33: Reference vs. tested instrument, June, NO_2

Table 95: Meteorological data (daily averages), November 2020

November 2020	Date	Avg. Ambient temperature [°C]	Rel. Humidity [%]	Air pressure [hPa]
1	01.11.2020	15.5	63.5	1004.9
2	02.11.2020	18.6	67.7	1002.3
3	03.11.2020	11.7	65.2	1013.9
4	04.11.2020	7.7	58.5	1023.0
5	05.11.2020	5.0	54.3	1030.3
6	06.11.2020	7.0	52.6	1025.3
7	07.11.2020	10.3	49.4	1016.8
8	08.11.2020	11.1	51.7	1014.6
9	09.11.2020	13.2	57.5	1015.1
10	10.11.2020	11.8	58.4	1016.9
11	11.11.2020	10.4	58.1	1017.0
12	12.11.2020	11.2	58.0	1010.7
13	13.11.2020	10.0	55.8	1010.1
14	14.11.2020	14.1	58.8	1008.6
15	15.11.2020	14.5	59.7	1000.6
16	16.11.2020	11.1	59.1	1005.0
17	17.11.2020	11.8	59.0	1016.4
18	18.11.2020	13.0	58.4	1015.4
19	19.11.2020	10.6	57.0	1013.3
20	20.11.2020	6.1	53.6	1025.7
21	21.11.2020	5.6	49.0	1023.9
22	22.11.2020	9.7	51.5	1018.4
23	23.11.2020	8.7	54.1	1019.9
24	24.11.2020	6.4	51.2	1016.6
25	25.11.2020	7.0	49.1	1010.4
26	26.11.2020	6.0	48.3	1013.0
27	27.11.2020	3.9	46.8	1012.1
28	28.11.2020	4.9	46.0	1012.4
29	29.11.2020	1.9	42.7	1017.6
30	30.11.2020	-0.4	39.4	1016.8

Table 96: Meteorological data (daily averages), December 2020

December 2020	Date	Avg. Ambient temperature [°C]	Rel. Humidity [%]	Air pressure [hPa]
1	01.12.2020	5.0	46.0	1006.8
2	02.12.2020	4.6	47.6	1009.3
3	03.12.2020	4.2	46.4	994.2
4	04.12.2020	6.3	45.4	978.7
5	05.12.2020	5.4	46.5	988.4
6	06.12.2020	3.9	45.4	992.0
7	07.12.2020	4.5	47.7	990.8
8	08.12.2020	4.2	46.4	995.2
9	09.12.2020	3.5	45.5	1001.3
10	10.12.2020	0.8	42.1	999.6
11	11.12.2020	3.1	41.0	989.2
12	12.12.2020	6.2	45.8	988.5
13	13.12.2020	7.8	49.7	1001.1
14	14.12.2020	8.3	47.6	1000.9
15	15.12.2020	8.4	50.4	1002.2
16	16.12.2020	8.5	53.5	1007.9
17	17.12.2020	6.9	49.8	1002.3
18	18.12.2020	5.3	52.7	1001.8
19	19.12.2020	6.4	53.2	1005.8
20	20.12.2020	6.8	50.8	999.7
21	21.12.2020	7.9	54.2	998.6
22	22.12.2020	8.2	55.8	1002.7
23	23.12.2020	7.7	53.6	1006.9
24	24.12.2020	10.2	54.2	1010.4
25	25.12.2020	7.4	51.4	1013.9
26	26.12.2020	9.3	51.4	1007.7
27	27.12.2020	10.2	53.0	1009.8
28	28.12.2020	7.6	51.6	1009.8
29	29.12.2020	13.3	56.8	1004.5
30	30.12.2020	11.8	60.0	1003.1
31	31.12.2020	7.4	57.5	1001.7

Table 97: Meteorological data (daily averages), January 2021

January 2021	Date	Avg. Ambient temperature [°C]	Rel. Humidity [%]	Air pressure [hPa]
1	01.01.2021	3.8	51.5	1015.7
2	02.01.2021	4.7	48.0	1010.2
3	03.01.2021	5.3	44.4	977.3
4	04.01.2021	3.7	43.7	993.0
5	05.01.2021	2.9	41.9	1007.3
6	06.01.2021	3.1	43.5	1007.0
7	07.01.2021	2.3	44.0	1004.8
8	08.01.2021	1.9	45.9	1007.0
9	09.01.2021	1.9	46.2	1015.1
10	10.01.2021	1.8	46.0	1016.4
11	11.01.2021	1.7	43.9	1011.9
12	12.01.2021	5.0	48.2	1001.8
13	13.01.2021	3.5	47.3	1007.9
14	14.01.2021	2.4	43.5	1010.7
15	15.01.2021	1.6	40.0	1018.4
16	16.01.2021	0.8	38.8	1016.5
17	17.01.2021	1.1	40.3	1011.0
18	18.01.2021	5.3	44.3	1014.2
19	19.01.2021	6.4	46.9	1002.9
20	20.01.2021	8.3	43.8	993.0
21	21.01.2021	9.3	45.3	984.5
22	22.01.2021	5.8	41.1	985.1
23	23.01.2021	4.5	37.0	987.1
24	24.01.2021	1.5	36.1	989.6
25	25.01.2021	1.3	34.4	996.5
26	26.01.2021	3.3	35.2	1007.8
27	27.01.2021	3.2	35.8	1005.0
28	28.01.2021	5.6	43.0	995.3
29	29.01.2021	8.9	48.2	988.5
30	30.01.2021	3.2	38.8	992.8
31	31.01.2021	1.3	31.3	992.8

Table 98: Meteorological data (daily averages), February 2021

February 2021	Date	Avg. Ambient temperature [°C]	Rel. Humidity [%]	Air pressure [hPa]
1	01.02.2021	1.2	33.6	993.8
2	02.02.2021	4.1	36.6	986.8
3	03.02.2021	7.4	42.4	992.7
4	04.02.2021	10.3	48.5	990.1
5	05.02.2021	8.6	44.0	1004.4
6	06.02.2021	8.9	43.3	1003.6
7	07.02.2021	5.8	44.3	999.0
8	08.02.2021	0.9	36.6	989.5
9	09.02.2021	-3.3	28.2	991.6
10	10.02.2021	-5.9	22.8	998.4
11	11.02.2021	-5.3	22.2	1005.3
12	12.02.2021	-3.0	21.6	1020.3
13	13.02.2021	-4.1	19.4	1024.9
14	14.02.2021	-2.9	18.5	1030.5
15	15.02.2021	-0.1	18.4	1028.5
16	16.02.2021	0.9	22.9	1018.0
17	17.02.2021	9.8	36.2	1008.2
18	18.02.2021	7.8	41.3	1009.1
19	19.02.2021	6.0	41.8	1004.1

Table 99: Meteorological data (daily averages), May 2021

May 2021	Date	Avg. Ambient temperature [°C]	Rel. Humidity [%]	Air pressure [hPa]
1	01.05.2021	9.9	62.2	1007.3
2	02.05.2021	8.2	62.2	1011.4
3	03.05.2021	9.4	53.9	1012.7
4	04.05.2021	11.8	52.7	996.4
5	05.05.2021	7.9	69.2	1000.0
6	06.05.2021	8.2	69.7	1000.9
7	07.05.2021	7.8	71.8	1007.6
8	08.05.2021	11.3	60.6	1008.6
9	09.05.2021	20.2	51.7	998.6
10	10.05.2021	19.7	51.2	999.5
11	11.05.2021	14.6	86.0	1002.5
12	12.05.2021	13.8	76.9	1004.9
13	13.05.2021	12.8	74.7	1001.5
14	14.05.2021	12.6	75.5	1001.6
15	15.05.2021	11.5	80.8	998.8
16	16.05.2021	11.2	81.5	996.2
17	17.05.2021	12.0	79.7	998.3
18	18.05.2021	11.6	81.5	1006.5
19	19.05.2021	11.8	76.1	1010.6
20	20.05.2021	14.4	66.0	1012.7
21	21.05.2021	14.7	55.9	1000.3
22	22.05.2021	11.5	69.5	999.5
23	23.05.2021	12.7	59.5	1007.3
24	24.05.2021	13.3	61.5	1004.2
25	25.05.2021	9.8	79.3	1007.3
26	26.05.2021	10.7	85.3	1007.0
27	27.05.2021	11.4	83.4	1011.5
28	28.05.2021	13.7	69.2	1017.1
29	29.05.2021	14.3	65.2	1018.7
30	30.05.2021	15.7	61.6	1019.8
31	31.05.2021	18.0	54.4	1015.4

Table 100: Meteorological data (daily averages), June 2021

June 2021	Date	Avg. Ambient temperature [°C]	Rel. Humidity [%]	Air pressure [hPa]
1	01.06.2021	16.7	54.8	1012.3
2	02.06.2021	20.8	49.1	1008.8
3	03.06.2021	19.9	78.8	1013.0
4	04.06.2021	21.2	80.5	1013.8
5	05.06.2021	17.7	88.8	1014.4
6	06.06.2021	15.8	87.1	1017.1
7	07.06.2021	18.0	78.9	1016.7
8	08.06.2021	19.3	70.6	1016.3
9	09.06.2021	20.6	66.5	1015.2
10	10.06.2021	22.1	55.8	1014.6
11	11.06.2021	22.5	59.7	1013.1
12	12.06.2021	20.1	67.2	1014.3
13	13.06.2021	17.6	58.2	1020.4
14	14.06.2021	21.5	53.4	1015.4
15	15.06.2021	22.1	60.1	1012.8
16	16.06.2021	24.8	54.7	1008.4
17	17.06.2021	28.0	51.4	1004.9
18	18.06.2021	27.7	54.9	1006.2
19	19.06.2021	26.3	53.8	1006.9
20	20.06.2021	23.1	69.0	1002.3
21	21.06.2021	19.6	77.6	1001.0
22	22.06.2021	15.0	84.5	1008.8
23	23.06.2021	16.4	86.5	1013.2
24	24.06.2021	17.5	81.0	1012.9
25	25.06.2021	19.1	63.5	1012.4
26	26.06.2021	19.9	64.1	1012.1
27	27.06.2021	21.0	69.7	1009.5
28	28.06.2021	22.1	79.8	1007.5
29	29.06.2021	21.0	74.7	1005.8
30	30.06.2021	16.7	87.1	1005.6

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

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 und Standorten

die Kompetenz nach DIN EN ISO/IEC 17025:2018 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; Bestimmung von Geräuschen in der Nachbarschaft; 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 17.06.2020 mit der Akkreditierungsnummer D-PL-11120-02. Sie besteht aus diesem Deckblatt, der Rückseite des Deckblatts und der folgenden Anlage mit insgesamt 48 Seiten.

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

Berlin, 17.06.2020

Im Auftrag Dipl.-Ing. Andrea Valbuena
Abteilungsleiterin

Die Urkunde samt Urkundenanlage gibt den Stand zum Zeitpunkt des Ausstellungsdatums wieder. Der jeweils aktuelle Stand des Geltungsbereiches der Akkreditierung ist der Datenbank akkreditierter Stellen der Deutschen Akkreditierungsstelle GmbH (DAkkS) zu entnehmen. https://www.dakks.de/content/datenbank-akkreditierter-stellen

Siehe Hinweise auf der Rückseite

Figure 34: 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 34: Certificate of accreditation according to EN ISO/IEC 17025:2005 - page 2

Annex 3:

Manual

User Manual

Model N500
CAPS NO_X Analyzer

with NumaView™ software

© TELEDYNE API (TAPI)
9970 CARROLL CANYON ROAD
SAN DIEGO, CALIFORNIA 92131-1106
USA

Toll-free Phone:	**+1 800-324-5190**
Phone:	**+1 858-657-9800**
Fax:	**+1 858-657-9816**
Email:	**api-sales@teledyne.com**
Website:	**http://www.teledyne-api.com/**

08977B DCN8302
12 June 2020

NOTICE OF COPYRIGHT

TRADEMARKS

SAFETY MESSAGES

Important safety messages are provided throughout this manual for the purpose of avoiding personal injury or instrument damage. Please read these messages carefully. Each safety message is associated with a safety alert symbol and is placed throughout this manual; the safety symbols are also located inside the instrument. It is imperative that you pay close attention to these messages, the descriptions of which are as follows:

WARNING: Electrical Shock Hazard

HAZARD: Strong oxidizer

GENERAL WARNING/CAUTION: Read the accompanying message for specific information.

CAUTION: Hot Surface Warning

Do Not Touch: Touching some parts of the instrument without protection or proper tools could result in damage to the part(s) and/or the instrument.

Technician Symbol: All operations marked with this symbol are to be performed by qualified maintenance personnel only.

Electrical Ground: This symbol inside the instrument marks the central safety grounding point for the instrument.

CAUTION

This instrument should only be used for the purpose and in the manner described in this manual. If you use this instrument in a manner other than that for which it was intended, unpredictable behavior could ensue with possible hazardous consequences.

NEVER use any combustible/explosive gas with this instrument!

For Technical Assistance regarding the use and maintenance of this instrument or any other Teledyne API product, contact Teledyne API's Technical Support Department:

Telephone: +1 800-324-5190
Email: api-techsupport@teledyne.com

or access any of the service options on our website at http://www.teledyne-api.com/

CONSIGNES DE SÉCURITÉ

Des consignes de sécurité importantes sont fournies tout au long du présent manuel dans le but d'éviter des blessures corporelles ou d'endommager les instruments. Veuillez lire attentivement ces consignes. Chaque consigne de sécurité est représentée par un pictogramme d'alerte de sécurité; ces pictogrammes se retrouvent dans ce manuel et à l'intérieur des instruments. Les symboles correspondent aux consignes suivantes :

AVERTISSEMENT : Risque de choc électrique

DANGER : Oxydant puissant

AVERTISSEMENT GÉNÉRAL / MISE EN GARDE : Lire la consigne complémentaire pour des renseignements spécifiques

MISE EN GARDE : Surface chaude

Ne pas toucher : Toucher à certaines parties de l'instrument sans protection ou sans les outils appropriés pourrait entraîner des dommages aux pièces ou à l'instrument.

Pictogramme « technicien » : Toutes les opérations portant ce symbole doivent être effectuées uniquement par du personnel de maintenance qualifié.

Mise à la terre : Ce symbole à l'intérieur de l'instrument détermine le point central de la mise à la terre sécuritaire de l'instrument.

MISE EN GARDE

Cet instrument doit être utilisé aux fins décrites et de la manière décrite dans ce manuel. Si vous utilisez cet instrument d'une autre manière que celle pour laquelle il a été prévu, l'instrument pourrait se comporter de façon imprévisible et entraîner des conséquences dangereuses.

NE JAMAIS utiliser de gaz explosive ou combustible avec cet instrument!

WARRANTY

WARRANTY POLICY (02024J)

Teledyne API (TAPI), a business unit of Teledyne Instruments, Inc., provides that:

Prior to shipment, TAPI equipment is thoroughly inspected and tested. Should equipment failure occur, TAPI assures its customers that prompt service and support will be available. (For the instrument-specific warranty period, please refer to the "Limited Warranty" section in the Terms and Conditions of Sale on our website at the following link: http://www.teledyne-api.com/terms_and_conditions.asp).

COVERAGE

After the warranty period and throughout the equipment lifetime, TAPI stands ready to provide on-site or in-plant service at reasonable rates similar to those of other manufacturers in the industry. All maintenance and the first level of field troubleshooting are to be performed by the customer.

NON-TAPI MANUFACTURED EQUIPMENT

Equipment provided but not manufactured by TAPI is warranted and will be repaired to the extent and according to the current terms and conditions of the respective equipment manufacturer's warranty.

PRODUCT RETURN

All units or components returned to Teledyne API should be properly packed for handling and returned freight prepaid to the nearest designated Service Center. After the repair, the equipment will be returned, freight prepaid.

The complete Terms and Conditions of Sale can be reviewed at http://www.teledyne-api.com/terms_and_conditions.asp

CAUTION – Avoid Warranty Invalidation

Failure to comply with proper anti-Electro-Static Discharge (ESD) handling and packing instructions and Return Merchandise Authorization (RMA) procedures when returning parts for repair or calibration may void your warranty. For anti-ESD handling and packing instructions please refer to the manual, Fundamentals of ESD, PN 04786, in its "Packing Components for Return to Teledyne API's Customer Service" section. The manual can be downloaded from our website at http://www.teledyne-api.com. RMA procedures can also be found on our website.

ABOUT THIS MANUAL

Note	**We recommend that all users read this manual in its entirety before operating the instrument.**

CONVENTIONS USED

In addition to the safety symbols as presented in the *Safety Messages* page, this manual provides *special notices* related to the careful and effective use of the instrument and related, pertinent information.

ATTENTION	**COULD DAMAGE INSTRUMENT AND VOID WARRANTY** **This special notice provides information to avoid damage to your instrument and possibly invalidate the warranty.**
Important	**IMPACT ON READINGS OR DATA** **Provides information about that which could either affect accuracy of instrument readings or cause loss of data.**
Note	**Provides information pertinent to the proper care, operation or maintenance of the instrument or its parts.**

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION, SPECIFICATIONS, APPROVALS, & COMPLIANCE

Teledyne API's Model N500 CAPS NO_x-NO_2-NO Analyzer uses Cavity-Attenuated Phase-Shift (CAPS) spectroscopy to render direct, true measurements of nitrogen dioxide (NO_2). By combining direct NO_2 measurements with highly efficient gas phase titration (GPT), the N500 converts and measures the NO sample gas component as NO_2, thus allowing for the measurement of total NOx. Furthering its accuracy and dependability is an auto-reference cycle to account and compensate for any potential baseline drift in the measured loss, that may be caused by varying environmental conditions.

CAPS technology is superior to the traditional chemiluminescence method in both speed and precision since the sampled NO_2 does not require catalytic conversion to calculate a difference measurement.

Economically, the Model N500 CAPS NO_X instrument is less costly to operate and maintain than traditional analyzers in that it uses less power and fewer components.

The section on Principles of Operation provides more detail on the behavior and technique of the CAPS method for NO_X measurement.

1.1. SPECIFICATIONS

Table 1-1. Specifications

Parameter	Description	
Ranges	Min: 0-5 ppb Max: 0-1 ppm NO_X (full scale user-selectable)	
Measurement Units	ppb, ppm, µg/m³, mg/m³ (user-selectable)	
Zero Noise	< 0.05 ppb (RMS)	
Span Noise	< 0.2% of reading + 50 ppt (RMS)	
Zero Drift	< 0.2 ppb / 24 hours	
Span Drift	< 0.5% of reading / 24 hours	
Lower Detectable Limit	< 0.1 ppb	
Response Time	< 60 Seconds to 95%	
Linearity	1% Full Scale	
Precision	0.5% of reading above 5 ppb	
Sample Flow Rate	1000 cc/min ±10%	
AC Power	Rating	Typical Power Consumption
	100 - 240 V~ 47-63 Hz 3.0 A	110 W
Power Entry Module Fuse	5.0 A, 250 V AC, 5 mm x 20 mm, SLO-BLO	

Parameter	Description
Communications	
Standard I/O	1 Ethernet: TCP/IP 1 RS-232 or RS-485 (user-configurable) (300 – 115,200 baud) 2 front panel USB device ports
Optional I/O	Universal Analog Output Board (all user-definable): 4 x isolated voltage outputs (5 V, 10 V) 3 x individually isolated current outputs (4-20 mA) Digital I/O Expansion Board includes: 3 x isolated digital input controls (fixed) 5 x isolated digital output controls (user-definable) 3 x form C relay alarm outputs (user-definable)
Operating Temperature	0-40 ºC (with US EPA approval)
Humidity Range	0-95% RH, Non-Condensing
Dimensions HxWxD	7” x 17” x 23.5” (178 x 432 x 597 mm)
Weight	33 lbs (15 kg)
Environmental Conditions	• Installation Category (Over Voltage Category) II Pollution Degree 2 • Intended for Indoor Use Only at Altitudes ≤ 2000m
Note: All specifications are based on constant conditions	

1.2. EPA DESIGNATION

Teledyne API’s Model N500 CAPS NOx analyzer is officially designated as US EPA Automated Equivalent Method, Designation Number EQNA- 0320-256.

The official List of Designated Reference and Equivalent Methods is published in the U.S. Federal Register, http://www3.epa.gov/ttn/amtic/criteria.html, and specifies the instrument’s settings and configurations.

1.3. SAFETY

IEC/EN 61010-1:2010 (3rd Edition), Safety requirements for electrical equipment for measurement, control, and laboratory use.

CE**:** 2014/95/EU, Low-Voltage Directive

1.4. EMC

IEC/EN 61326-1, Class A Emissions/Industrial Immunity

FCC 47 CFR Part 15B, Class A Emissions

CE**:** 2014/108/EU, Electromagnetic Compatibility Directive

2. GETTING STARTED

This section addresses unpacking, connecting, and initializing the instrument, getting an overview of the menu system, and setting up/configuring the functions.

2.1. UNPACKING

CAUTION - GENERAL SAFETY HAZARD

To avoid personal injury, always use two persons to lift and carry the analyzer.

ATTENTION

COULD DAMAGE INSTRUMENT AND VOID WARRANTY

Printed Circuit Assemblies (PCAs) are sensitive to electro-static discharges too small to be felt by the human nervous system. Failure to use Electro-Static Discharge (ESD) protection when working with electronic assemblies will void the instrument warranty. Refer to the manual, Fundamentals of ESD, PN 04786, which can be downloaded from our website at http://www.teledyne-api.com.

ATTENTION

COULD DAMAGE INSTRUMENT AND VOID WARRANTY

Do not operate this instrument without first removing dust plugs from SAMPLE and EXHAUST ports on the rear panel.

Note

Teledyne API recommends that you store shipping containers and materials for future use if/when the instrument should be returned to the factory for repair and/or calibration service. See Warranty statement in this manual and Return Merchandise Authorization (RMA) on our Website at http://www.teledyne-api.com.

Verify that there is no apparent external shipping damage. If damage has occurred, please advise the shipper first, then Teledyne API.

Included with your instrument is a printed record of the final performance characterization performed on your instrument at the factory. This record, titled Final Test and Validation Data Sheet, is an important quality assurance and calibration record and should be placed in the quality records file for this instrument.

With no power to the unit, carefully remove the top cover of the instrument and check for internal shipping damage by carrying out the following steps:

1. Carefully remove the top cover and check for internal shipping damage.
    a. Remove the screws located on the instrument's sides.
    b. Slide the cover backward until it clears the instrument's front bezel.
    c. Lift the cover straight up.
2. Inspect the interior of the instrument to ensure all circuit boards and other components are intact and securely seated.
3. Check the connectors of the various internal wiring harnesses and pneumatic hoses to ensure they are firmly and securely seated.
4. Verify that all of the optional hardware ordered with the unit has been installed. These are listed on the paperwork accompanying the instrument.

WARNING – ELECTRICAL SHOCK HAZARD

Never disconnect PCAs, wiring harnesses or electronic subassemblies while under power.

2.1.1. VENTILATION CLEARANCE

Whether the instrument is set up on a bench or installed in a rack, be sure to leave sufficient ventilation clearance.

Table 2-1. Ventilation Clearance

AREA	MINIMUM REQUIRED CLEARANCE
Back of the instrument	10 cm / 4 in
Sides of the instrument	2.5 cm / 1 in
Above and below the instrument	2.5 cm / 1 in

2.2. INSTRUMENT LAYOUT

Instrument layout includes front panel, rear panel connectors, and the internal chassis layout.

2.2.1. FRONT PANEL

The front panel (Figure 2-1) includes two USB ports for peripheral device connections, which can be used with mouse and keyboard as alternatives to the touchscreen interface, or with flash drive for uploads/downloads (devices not included).

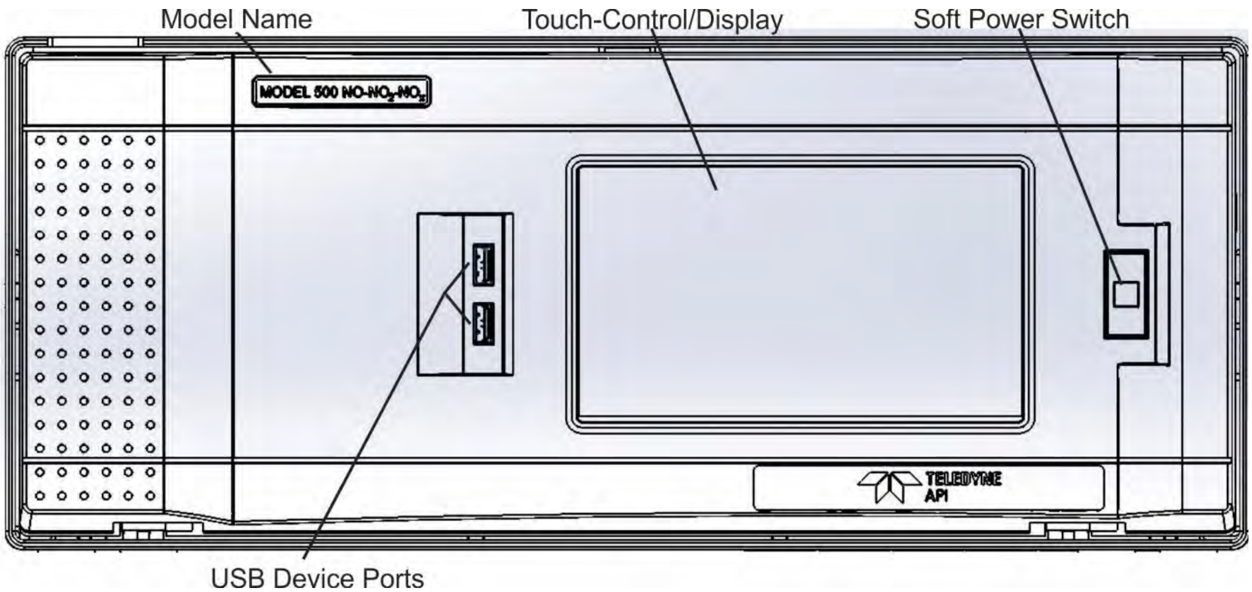


Figure 2-1. Front Panel Layout

2.2.2. REAR PANEL

Figure 2-2 shows the layout of the rear panel.

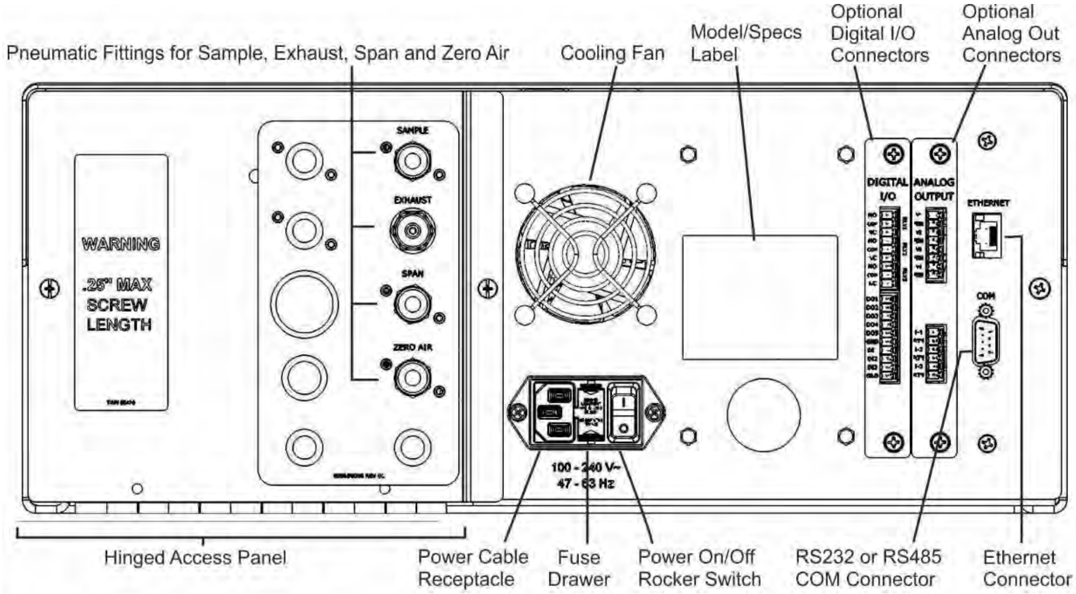


Figure 2-2. Rear Panel Layout

Table 2-2. Rear Panel Description

COMPONENT	FUNCTION
Model/specs label	Identifies the analyzer model number and provides power specs.
SAMPLE	Connect a gas line from the source of sample gas here. Calibration gases can also enter here on units without zero/span/shutoff valve options installed.
EXHAUST	Connect an exhaust gas line of not more than 10 meters long here that leads outside the shelter or immediate area surrounding the instrument. The line must be ¼" tubing or greater.
SPAN	On units with zero/span valve option installed, connect a gas line to the source of calibrated span gas here.
ZERO AIR	On units with zero/span valve option installed, attach a gas line to the source of zero air here. If a permeation oven, also known as internal zero/span valve (IZS), option is installed attach the zero air scrubber here.
Cooling fan	Pulls ambient air into chassis through side vents and exhausts through rear.
Power cable connector	Connector for three-prong cord to apply AC power to the analyzer. **CAUTION! The cord's power specifications (specs) MUST comply with the power specs on the analyzer's rear panel label**
Power On/Off Switch	Rocker switch to power unit on or off. **CAUTION!** Prior to powering OFF, use front panel button for preliminary internal "soft" power-down to protect components from damage.
Fuse drawer	For circuit protection.
ANALOG OUT Option	For voltage or current loop outputs to a strip chart recorder and/or a data logger.
DIGITAL I/O Option	For remotely activating the zero and span calibration modes.
ETHERNET	Connector for network or Internet remote communication, using Ethernet cable.
COM	Serial communications port for RS-232 or RS-485.

2.2.3. INTERNAL CHASSIS

Figure 2-3 shows the internal chassis layout.

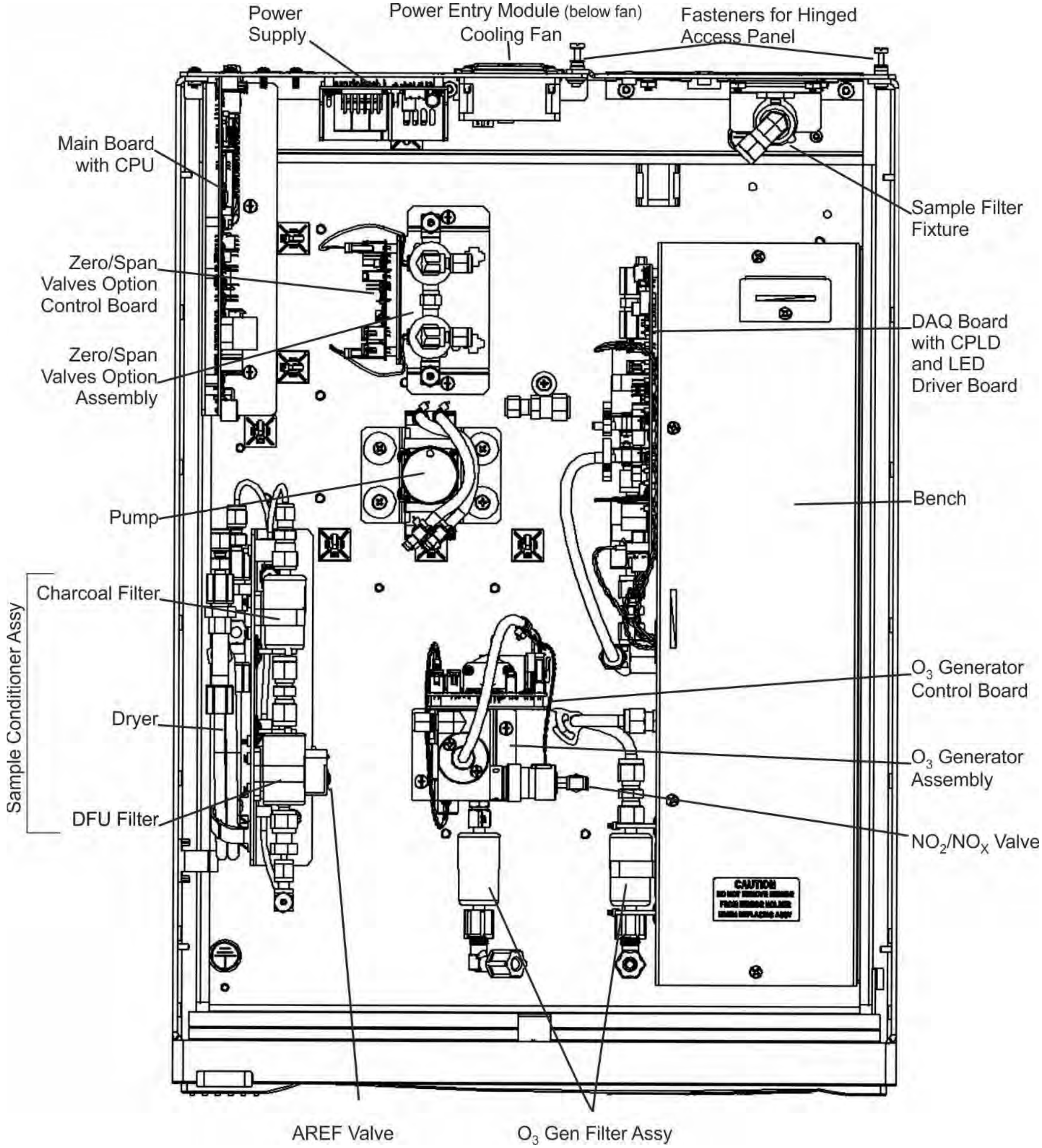


Figure 2-3. Internal Chassis Layout

2.3. CONNECTIONS AND STARTUP

This section presents the electrical (Section 2.3.1) and pneumatic (Section 2.3.2) connections for setting up and preparing the instrument for operation (Section 2.3.3).

2.3.1. ELECTRICAL CONNECTIONS

Note **To maintain compliance with EMC standards, cable length must be no greater than 3 meters for all I/O connections.**

WARNING – Electrical Shock Hazard

- **High Voltages are present inside the instrument's case.**
- **Power connection must have functioning ground connection.**
- **Do not defeat the ground wire on power plug.**
- **Turn off instrument power before disconnecting or connecting electrical subassemblies.**
- **Do not operate with cover off.**

CAUTION – Avoid Damage to the Instrument

Ensure that the AC power voltage matches the voltage indicated on the instrument's rear panel before plugging it into line power.

2.3.1.1. CONNECTING POWER

ATTENTION **COULD DAMAGE INSTRUMENT AND VOID WARRANTY**

Never power off the instrument from the rear panel Hard Power switch before first placing the internal computerized components into deep sleep mode through the front panel Soft Power switch. Press and momentarily hold the front panel Soft Power switch, which triggers the Supervisory chip to safely shut down the internal components. The LED state then changes from solid lit to blinking, at which time the rear panel Hard Power switch can be used to power off the instrument.

Attach the power cord between the instrument's AC power connector and a power outlet capable of carrying at least the rated current at your AC voltage range and ensure that it is equipped with a functioning earth ground. It is important to adhere to all safety and cautionary messages.

2.3.1.2. Connecting Analog Outputs Option

The optional rear panel Analog Output board offers several channels that can be mapped to reflect various operating values in the analyzer, including concentration values, temperatures, pressures, etc. These mappings are not configured by default and must be set by the user.

The four **voltage** outputs (0-5 V or 0-10 V) are isolated from the instrument but share a common ground. The three **current** outputs are individually isolated from each other and from the instrument.

To access these signals, attach a strip chart recorder and/or data-logger to the appropriate analog output connections, and configure through the Setup>Analog Outputs menu.

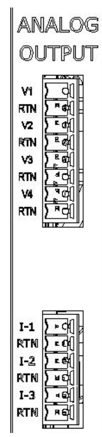


Figure 2-4. Analog Outputs Connectors Panel Option

Table 2-3. Analog Output Pin Assignments

PIN	OUTPUT	DESCRIPTION
Isolated Voltage Outputs		
V1	V +	User definable through the Setup>Analog Outputs menu.
RTN	Ground	
V2	V +	
RTN	Ground	
V3	V +	
RTN	Ground	
V4	V +	
RTN	Ground	
Isolated Current Outputs		
I-1	I Out +	User definable through the Setup>Analog Outputs menu.
RTN	I Out -	
I-2	I Out +	
RTN	I Out -	
I-3	I Out +	
RTN	I Out -	

2.3.1.3. Connecting the Digital I/O Expansion Board Option

The connections on this board include three relay alarms, five digital outputs, and three isolated digital input controls. The **Relays** can be mapped to reflect various internal instrument conditions and states. The **Outputs** are isolated from the instrument and consist of open collector transistors with a common ground; they can be mapped to reflect various internal instrument conditions and states; they can be used to interface with devices that accept logic-level digital inputs, such as Programmable Logic Controllers (PLCs). The **Inputs** are also isolated but share the same ground as the Outputs; they will work with relays, open collectors, or 3.3 V – 24 V logic. Pull low to activate. DI1 and DI2 are fixed (not mappable) for remote zero and span calibrations.

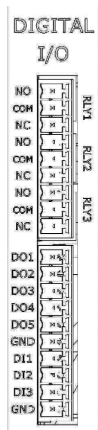


Figure 2-5. Digital I/O Connector Panel Option

Table 2-4. Digital Input/Output Pin Assignments

PIN	DESCRIPTION	
Relays		
NO	RLY1	Relay Alarms, user-configurable through the Setup>Digital Outputs menu.
COM		
NC		
NO	RLY 2	
COM		
NC		
NO	RLY 3	
COM		
NC		
Digital Outputs and Inputs		
DO1	Digital Outputs mappable in the Setup>Digital Outputs menu, and viewable in the Utilities>Diagnostics>Digital Outputs menu	
DO2		
DO3		
DO4		
DO5		
GND	Ground	
DI1	Digital Input1 = Remote Zero Cal Digital Input2 = Remote Span Cal (Digital Input3 not used) View status in Utilities>Diagnostics>Digital Inputs menu	
DI2		
DI3		
GND	Ground	

2.3.1.4. CONNECTING COMMUNICATIONS INTERFACES

ETHERNET CONNECTION

For network or Internet communication with the analyzer, connect an Ethernet cable from the analyzer's rear panel Ethernet interface connector to an Ethernet port. Although the analyzer is shipped with DHCP enabled by default, it should be manually configured with a static IP address.

SERIAL CONNECTION

Received from the factory, the analyzer COM port is set up for RS-232 communications with data communication equipment (DCE). This port can be reconfigured for RS-232 communications with data terminal equipment (DTE) or with RS-485 by jumpering the pins on JP1 as indicated in Table 2-5 (view/edit software settings Table 2-12).

WARNING – ELECTRICAL SHOCK HAZARD

Disconnect power before performing any operation that requires entry into the interior of the analyzer.

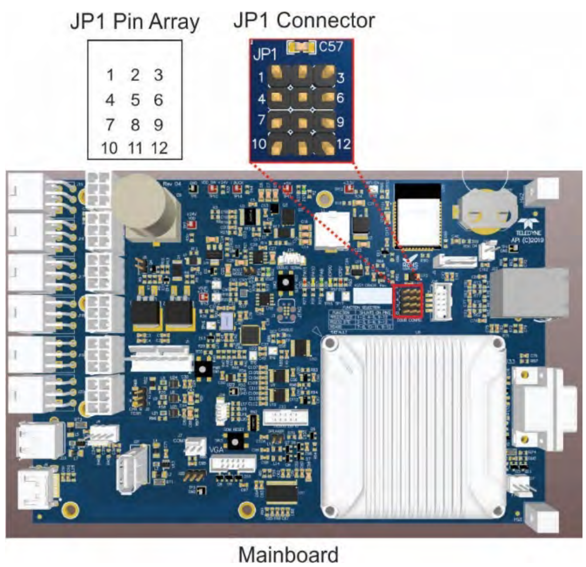


Figure 2-6. Mainboard JP1 Location and Pin Arrangements

Table 2-5. JP1 Configurations for Serial Communication

Function	Jumpers	DSub Pins	
		2	3
DCE RS232 (default)	1-2, 4-5, 9-12	232Tx	232Rx
DTE RS232	2-3, 5-6, 9-12	232Rx	232Tx
RS485	7-8, 10-11, 9-12	485A(-)	485B(+)

View/edit the Communications parameters in the Setup>Comm>COM1 menu.

RS-232

- **Baud rate**: 115200 bits per second (baud)
- **Data Bits**: 8 data bits with 1 stop bit
- **Parity**: None

RS-485

- **Baud rate**:19200 bits per second (baud)
- **Data Bits**: 8 data bits with 1 stop bit
- **Parity**: None

2.3.2. PNEUMATIC CONNECTIONS

This section provides pneumatic connection and setup instructions for basic and valve option configurations. Pneumatic flow diagrams are shown in Section 2.3.3. Calibration instructions are provided in Section 4.

Before making the pneumatic connections, carefully note the following cautionary and special messages:

CAUTION – General Safety Hazard

Do not vent calibration gas, exhaust gas or sample gas into enclosed areas.

CAUTION – General Safety Hazard

In units with a permeation tube option installed, vacuum pump must be connected and powered on to maintain constant gas flow though the analyzer at all times. Insufficient gas flow allows gas to build up to levels that will contaminate the instrument or present a safety hazard to personnel.

Remove the permeation tube when taking the analyzer out of operation and store in sealed container (use the original shipping packaging).

(See Section 5.6.4 for instructions on how to remove the permeation tube when the unit is not in operation).

ATTENTION

COULD DAMAGE INSTRUMENT AND VOID WARRANTY

VENT PRESSURIZED GAS:

When any gas (span, zero air, sample) is received from a pressurized manifold, always provide a vent to equalize the pressure with the ambient atmosphere before it enters the instrument to ensure that the gases input do not exceed the instrument's maximum inlet pressure, as well as to prevent back diffusion and pressure effects

REMOVE DUST PLUGS:

Remove dust plugs from rear panel exhaust and supply line fittings before powering on the instrument.

Keep dust plugs for reuse in future storage or shipping to prevent debris from entering the pneumatics.

Important

IMPACT ON READINGS OR DATA

- **Sample and calibration gases should only come into contact with PTFE tubing.**
- **Do NOT place any mufflers or filters downstream of the pump, i.e., external to the instrument.**
- **Run a leak check once the appropriate pneumatic connections have been made; check all pneumatic fittings for leaks per Section 5.4.12.1 (or Section 5.4.12.2 for detailed check if any leaking is suspected).**

2.3.2.1. Critical Tubing, Pressure, Venting and Exhaust Requirements

The requirements presented in this section apply to all pneumatic connection instructions.

Tubing:

- PTFE material
- Outer diameter (OD) minimum ¼"
- Min/max length 2 meters to 10 meters

Pressure:

- All Sample gas pressure must be at ambient atmospheric pressure, no greater than 1.0 psig.

Venting (to prevent back diffusion and pressure effects):

- Run tubing outside the enclosure or at least away from immediate area surrounding the instrument.

Exhaust Outlet:

- Run tubing outside the enclosure.

Calibration Gas Sources:

- The source of calibration gas or zero air is also attached to the **SAMPLE** inlet, but only when a calibration operation is actually being performed.

2.3.2.2. Basic Connections from Calibrator

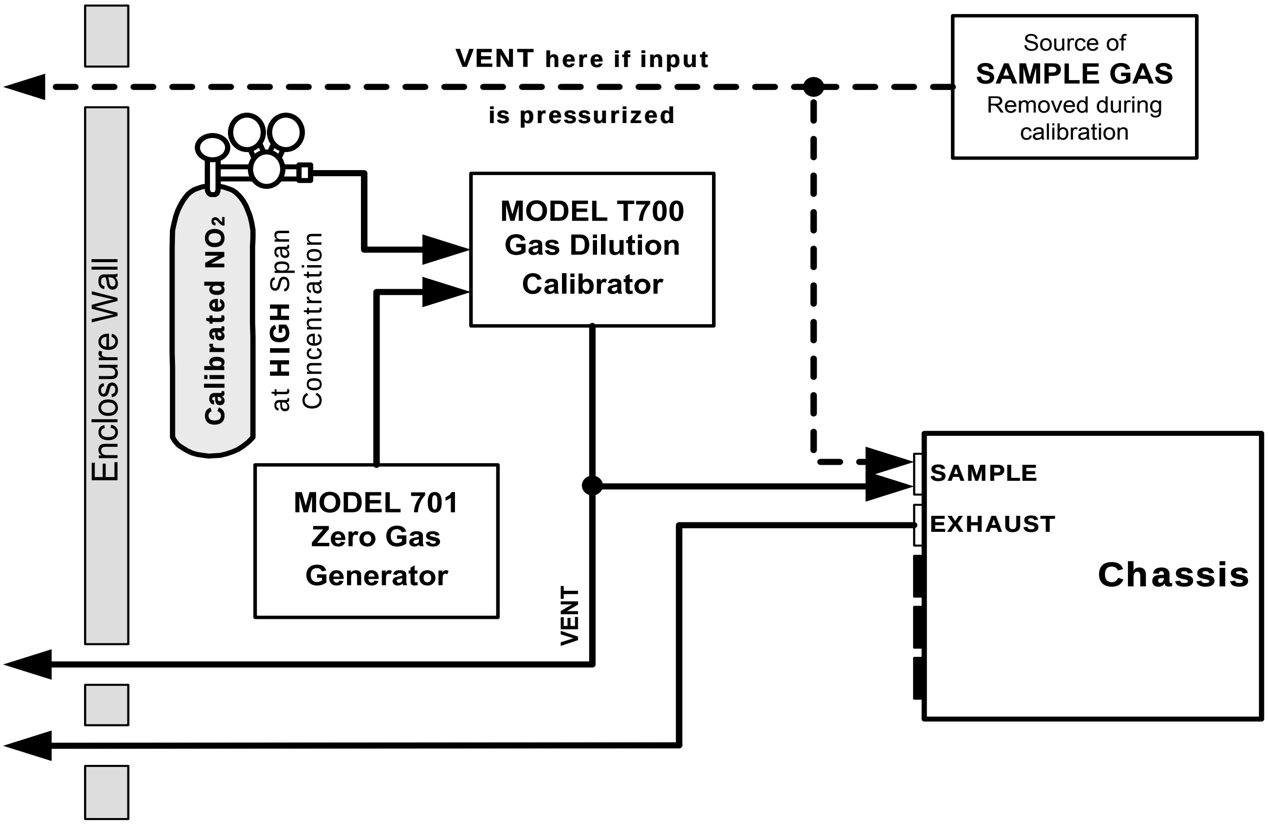


Figure 2-7. Gas Line Connections from Calibrator – Basic Configuration

For the analyzer's basic configuration, in addition to tubing, pressure, venting, and exhaust requirements set out in Section 2.3.2.1, attach the following pneumatic lines:

Sample Gas Source

Connect a sample gas line to the SAMPLE inlet.

Calibration Gas Sources

NO_2 CAL GAS & ZERO AIR SOURCES: The source of calibration gas is attached to the SAMPLE inlet, but only when a calibration operation is actually being performed.

Venting

Vent the output of the calibrator if calibrator not already vented.

Exhaust Outlet

Attach an exhaust line to the EXHAUST outlet fitting and vent outside the shelter.

2.3.3. PNEUMATIC FLOW DIAGRAMS

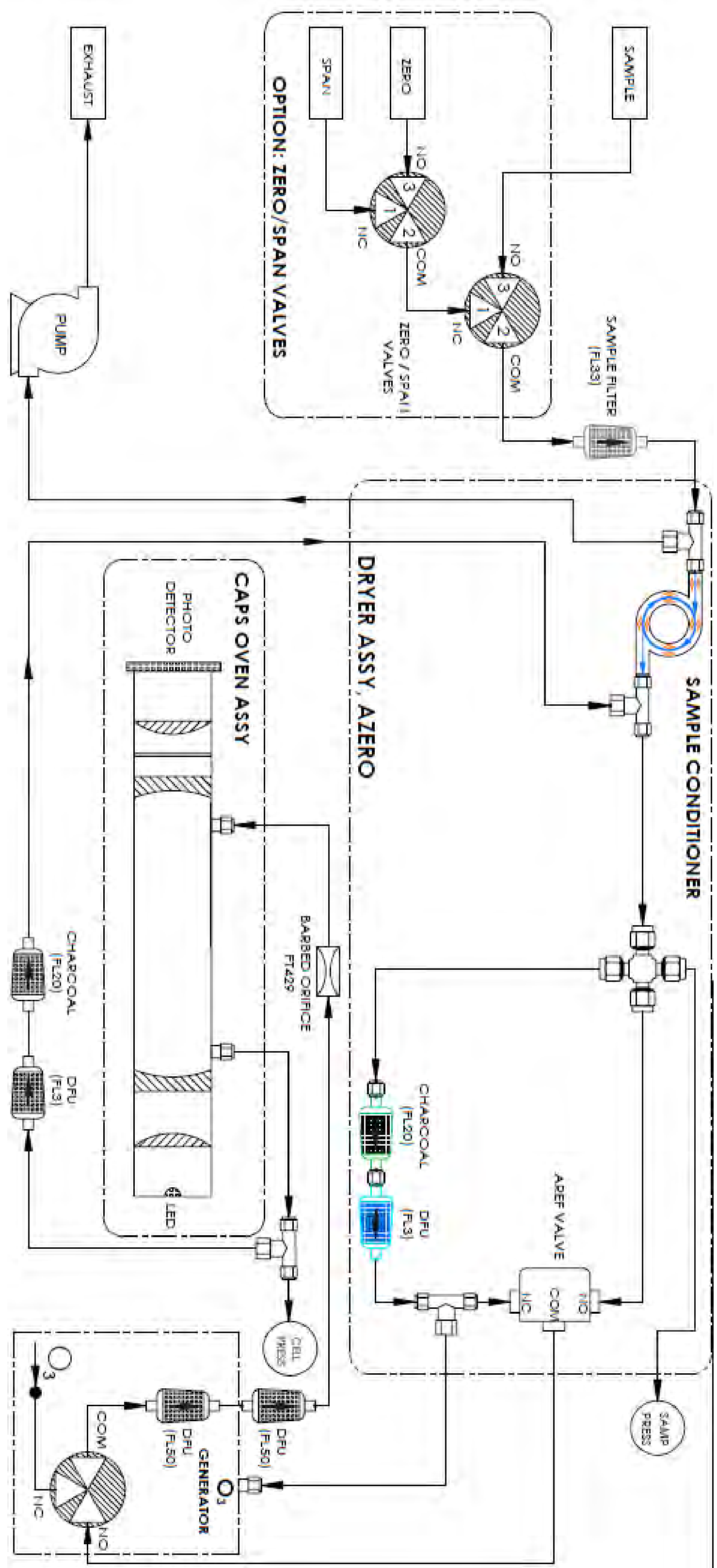


Figure 2-8. Pneumatic Flow Diagram including Zero/Span Valve Option

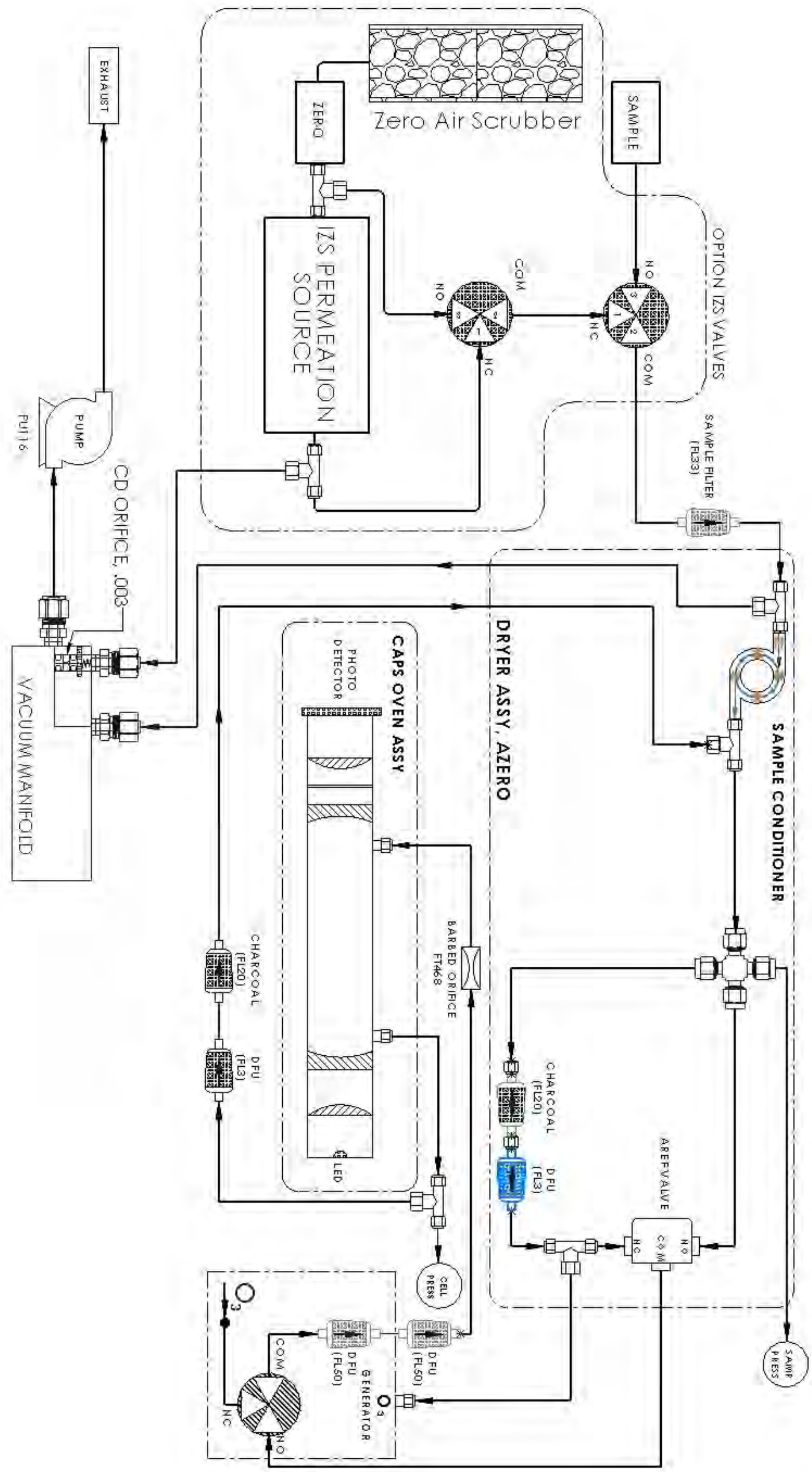


Figure 2-9. Pneumatic Flow Diagram including IZS Valve Option

2.3.4. STARTUP, FUNCTIONAL CHECKS AND CALIBRATION

We recommend reading Section 6 to become familiar with the principles of operation. .

Note	It is expected that all cautionary messages are being followed.

The front panel Soft Power switch has a status LED that indicates whether:

- instrument is powered down (LED off)
- instrument powered on and internal components in deep sleep mode (LED blinking, achieved by pressing and momentarily holding the soft power button)
- instrument powered on and internal components are operating (LED solid lit, achieved when first powered up; must place in deep sleep mode before power off)

When the instrument is first started (Section 2.3.4.1), check its functionality (Section 2.3.4.3) and run an initial calibration (Section 2.3.4.4). Section 2.4 introduces the menu system, and Section 2.5 provides setup/customization instructions.

2.3.4.1. STARTUP

Upon initial startup, a sequence of status screens (Figure 2-10) appear prior to the Home page (Figure 2-11).

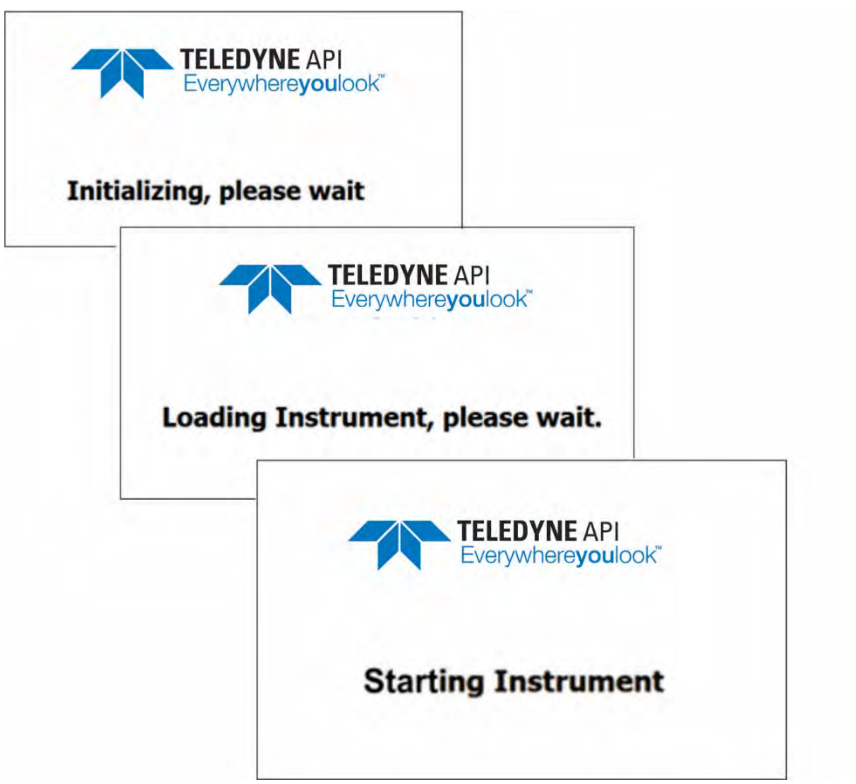


Figure 2-10. Status Screens at Startup

Upon any startup, this instrument should warm up for approximately one hour before reliable measurements can be taken.

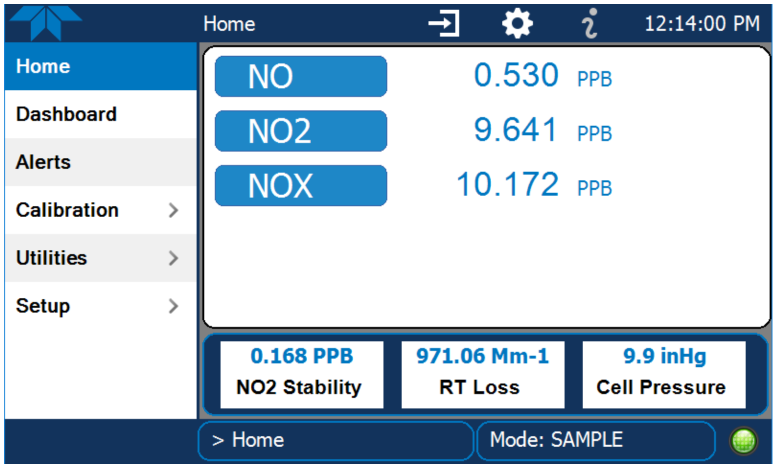


Figure 2-11. Home Page Example

2.3.4.2. ALERTS: WARNINGS AND OTHER MESSAGES

Because internal temperatures and other conditions may be outside the specified limits during the warm-up period, the software will suppress most Alerts for 45 minutes after power up. The Alerts page (Figure 2-12) shows the status of any active warning conditions or user-configured Events. (Section 2.4.3 provides more detailed information about Alerts, and Section 2.5.2 addresses Events).

Alerts can be viewed and cleared via either the Alerts menu or the Alerts shortcut (Caution symbol, bottom right corner of the screen). Although these alerts can be cleared from the Active Alerts page, a history of all alerts remains in the Utilities>Alerts Log page.

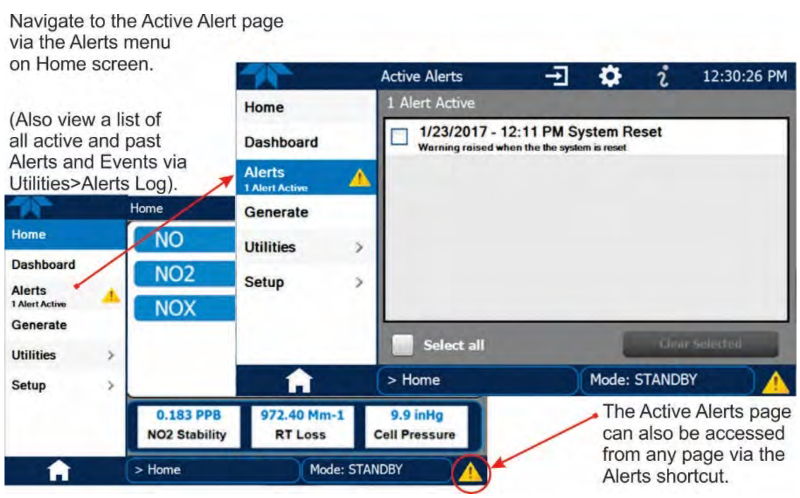


Figure 2-12. Viewing Active Alerts Page

If Alerts about warning conditions persist after the warm-up period or after being cleared, investigate their cause using the troubleshooting guidelines in Section 5.7.1.

2.3.4.3. Functional Checks

After warm-up, verify that the software properly supports any hardware options that are installed (Setup>Instrument menu), and that the instrument is functioning within allowable operating parameters. View the Dashboard page to check that parameters show expected/reasonable values. (If any functional parameters are not displayed, configure the Dashboard through the Setup>Dashboard menu to add them; see Section 2.4.2).

These functions are also useful tools for diagnosing problems (information provided in Section 5.7.2).

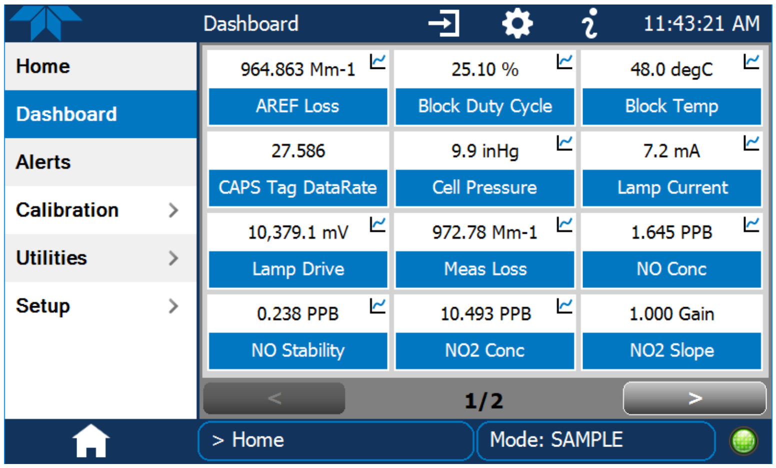


Figure 2-13. Sample Dashboard Page

2.3.4.4. Calibration

Before operation begins, the analyzer requires zero and span calibrations followed by a Titration Efficiency (TE) check. Also, any time an analyzer is moved, or its configuration changed, it must be calibrated. The method for performing a calibration differs slightly depending on whether or not any of the available internal valve options are installed. Follow the appropriate calibration instructions presented in Section 4.

2.4. MENU OVERVIEW

Table 2-6 describes the main menus and provides cross-references to the respective sections with configuration details.

Table 2-6. Menu Overview

MENU		DESCRIPTION	LOCATION
Home		View and plot concentration readings and other selectable parameter values (Figure 2-15).	Section 2.4.1
Dashboard		View user-selected parameters and their values, some of which can be displayed in a live-plot graph (Figure 2-16).	Section 2.4.2
Alerts		View and clear active Alerts that were triggered by factory-defined Events as well as user-defined Events. (Active and past Alerts are recorded in the Utilities>Alerts Log).	Section 2.4.3
Calibration		Run calibrations on the NO_2 and NOx channels.	Sections 2.4.4 and 4
Utilities		View logs, download data and firmware updates, copy configurations between instruments, and run diagnostics.	Section 2.4.5
Setup		Configure a variety of features and functions through these submenus for customized operation.	Section 2.5
	Datalogging	Track and record concentration and calibration data and selectable diagnostic parameters, the reports for which can be viewed in the Utilities>Datalog View menu (Section 2.4.5) and downloaded to a flash drive via the Utilities>USB Utilities menu (Section 2.4.5). Also, select configured Events (Section 2.5.2) and create customized triggers for data logging functions.	Section 2.5.1
	Events	Select parameters and define the conditions by which they are to be flagged and recorded in the Alerts log (Section 2.4.3) when they are triggered. Once configured, Events can be used to trigger Datalogs. (Section 2.5.1). Note that some Events are predefined and are not editable.	Section 2.5.2
	Dashboard	Monitor instrument functionality (Figure 2-13) via selectable parameters.	Section 2.5.3
	Auto Cal (with valve options)	When zero/span valve options installed, configure sequences for automatic calibration functions.	Section 4.3
	Vars	Manually adjust several software variables that define specific operational parameters.	Section 2.5.5
	Homescreen	Select up to three parameters to be displayed in the meters (Figure 2-14).	Section 2.5.6
	Digital I/O (option)	Map the rear-panel digital outputs to a variety of voltage or current signals present in the instrument to monitor the status of operating conditions or custom Events.	Section 2.5.7
	Analog Outputs (option)	Send user-selected parameter readings in the form of user-defined voltage or current loop signals as outputs to a strip chart recorder and/or the data logger.	Section 2.5.8
	Instrument	View product and system information, including list of options, if any; view network settings; view/adjust Date and Time settings*; and check for firmware updates when connected to a network that is connected to the Internet. *Time Zone change requires special procedures (Section 5.5).	Section 2.5.7
	Comm	View and configure network and serial communications.	Section 2.5.10

2.4.1. HOME PAGE

Figure 2-14 presents an orientation to the main display screen; Figure 2-15 shows that pressing the gas name or its concentration value or a meter below displays a live plot of their respective readings. Section 2.5.6 provides configuration instructions.

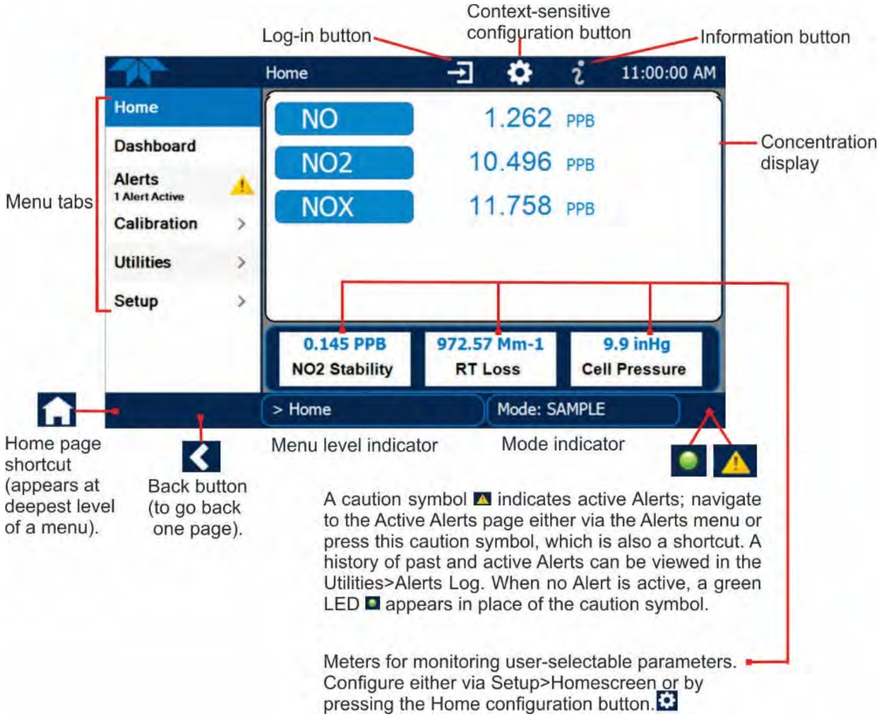


Figure 2-14. User Interface Orientation

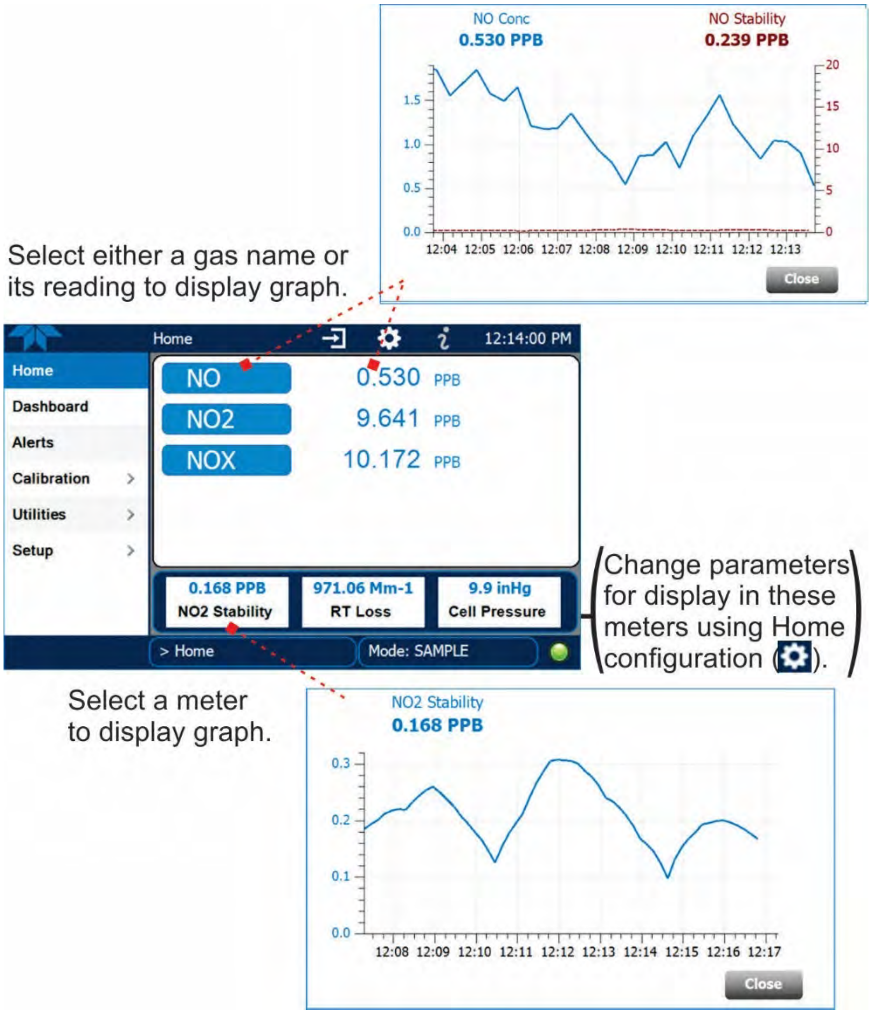


Figure 2-15. Concentration and Stability Graph (top) and Meter Graph (bottom)

2.4.2. DASHBOARD

The Dashboard displays an array of user-selectable parameters and their values (Section 2.5.3 provides configuration instructions). If there is a graphing icon in the upper right corner of a parameter, pressing that parameter displays a live plot of its readings as in Figure 2-16.

Figure 2-16. Dashboard Page

2.4.3. ALERTS

Alerts are notifications triggered by specific criteria having been met by either factory-defined conditions (standard and not editable) or user-defined Events (Section 2.5.2). The Active Alerts page shows the status of any active warning conditions or Events that have been triggered.

When Alerts are triggered, a caution symbol appears in both the Alerts menu tab and in the bottom right corner of the software interface, which serves as a shortcut to the Alerts page from any other page. View a list of currently active Alerts by pressing either the Alerts menu on the Home screen or by pressing the Alerts shortcut (Figure 2-17).

While Alerts can be cleared from the Active Alerts page, they remain recorded in the Utilities>Alerts Log menu.

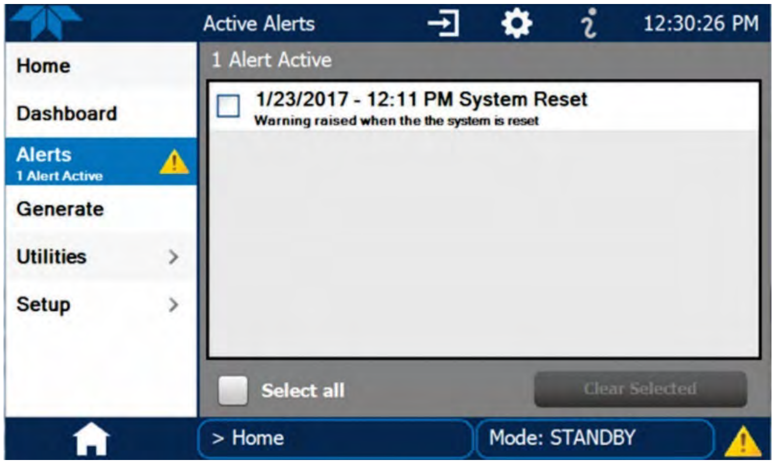


Figure 2-17. Active Alerts Page

Alerts can be configured as either latching (appears in Active Alerts screen when Event is triggered and must be cleared by the user) or non-latching (Active Alerts screen continuously updates based on the Event criteria, clearing on its own). See Section 2.5.2.

To clear Alerts from the Active Alerts page, either check individual boxes to choose specific Alerts, or check the Select All box to choose all Alerts, then press the Clear Selected button.

When all Alerts are cleared, the Alerts menu tab no longer shows the caution symbol, and a green LED replaces the caution symbol in the bottom right corner of the interface (Figure 2-18). However, Alerts can reappear if the conditions causing them are not resolved. For troubleshooting guidance, refer to Section 5.7.

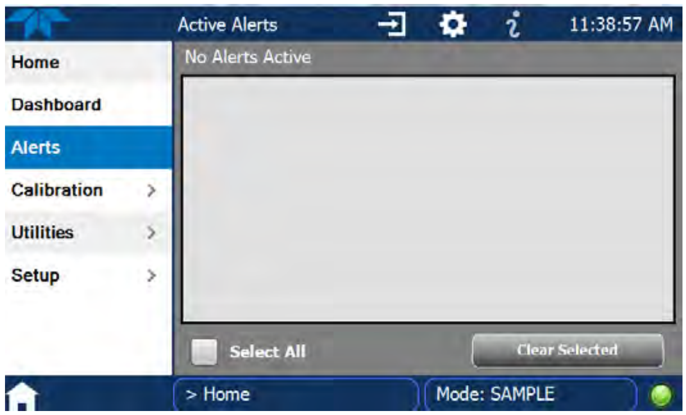


Figure 2-18. Active Alerts Cleared

Alerts and Events remain recorded in the Utilities>Alerts Log (Figure 2-19).

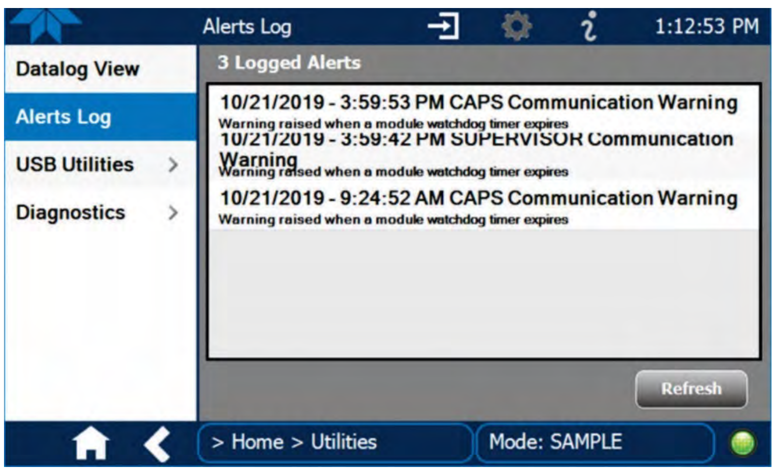


Figure 2-19. Utilities>Alerts Log of Active and Past Alerts and Events

2.4.4. CALIBRATION

The Calibration menu is used for zero/span/multipoint calibrations and for external calibration with valve options installed. Calibration procedures are presented in Section 4.

2.4.5. UTILITIES

The Utilities menu has a variety of functions as described next in Table 2-7.

Table 2-7. Utilities Submenu Descriptions

UTILITIES MENU	DESCRIPTION	
Datalog View	Displays the data logs that were configured via the Setup>Data Logging menu. From this list a log can be selected and filters applied to view the desired data. (For details on setting up and running the Data Logger, see Section 2.5.1).	
Alerts Log	Displays a history of alerts that are triggered by factory-defined and user-defined Events, such as warnings and alarms (See Section 2.5.2 for Events configuration).	
USB Utilities	Serves multiple purposes using a flash drive connected to the instrument's front panel USB port: • download data from the instrument's Data Acquisition System (DAS), the Data Logger, to a flash drive (Section 2.5.1.3) • update firmware (Section 5.3) • transfer instrument configuration from/to other same-model instruments (Section 2.6) • download a basic operation functionality report (Section 5.3).	
Diagnostics	Provides access to various pages that facilitate troubleshooting.	
	Analog Outputs (Option)	Show the voltage or current signals for the functions selected and configured in the Setup>Analog Outputs menu. (Section 2.3.1.2 presents the rear panel connections).
	Digital I/O (Option)	Show whether specific available features are turned ON or OFF; input controls are fixed; output controls and relays are configurable in the Setup> Digital Outputs menu. (Section 2.3.1.3 presents the rear panel connections).
	Manual AREF	At 20 minutes after power up and periodically thereafter when in Sample mode, the analyzer conducts a background measurement, known as an auto reference (AREF), whereby the sample is routed through an internal charcoal scrubber prior to the AREF valve. This measurement accounts for drift in the baseline loss. A manual AREF is recommended prior to initial calibration (Section 4.2) or after general maintenance. Please note that AREF becomes disabled during calibration if the instrument stays in calibration mode (CALZ or CALS) for longer than it would normally take to run a calibration. To ensure that AREF is enabled, return to Sample mode after conducting a calibration.
	O3 Gen Override	Used to override the Ozone Generator state when needed, such as for service (Section 5.7.7.3).

2.4.6. SETUP

The Setup menu is used to configure the instrument's various features, functions, and data log. Section 2.5 provides details for the menus under Setup.

2.5. SETUP MENU: FEATURES/FUNCTIONS CONFIGURATION

Use the Setup menu to configure the instrument's software features, to gather information on the instrument's performance, and to configure and access data from the Datalogger, the instrument's internal data acquisition system (DAS). Once the setups are complete, the saved configurations can be downloaded to a USB drive through the Utilities>USB Utilities menu and uploaded to other instruments of the same model (Section 2.6).

2.5.1. SETUP>DATA LOGGING (DATA ACQUISITION SYSTEM, DAS)

The Datalogger can be configured to capture and store user-defined data, which then can be viewed in the Alerts page, if elected, as well as downloaded from the instrument to a USB flash drive or using NumaView™ Remote software for examination and analysis.

Figure 2-20 shows a new log; Figure 2-21 shows a sample existing log, which can be edited or deleted, and Figure 2-22 provides illustrated instructions for setting up a new log, with Sections 2.5.1.1 and 2.5.1.2 providing additional details.

To transfer captured instrument data to a flash drive, see Section 2.5.1.3.

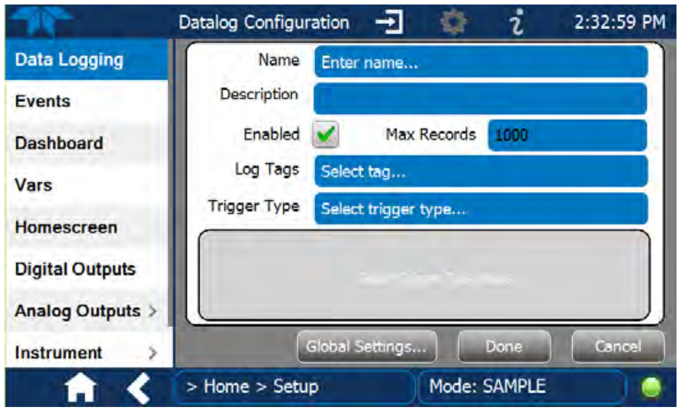


Figure 2-20. Datalog Configuration, New Log Page

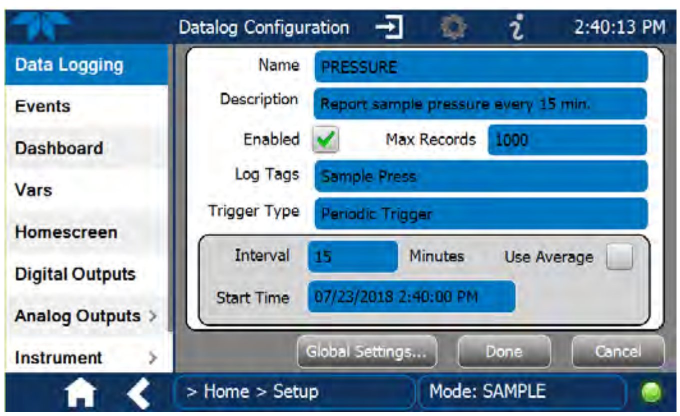


Figure 2-21. Datalog Configuration, Existing Log

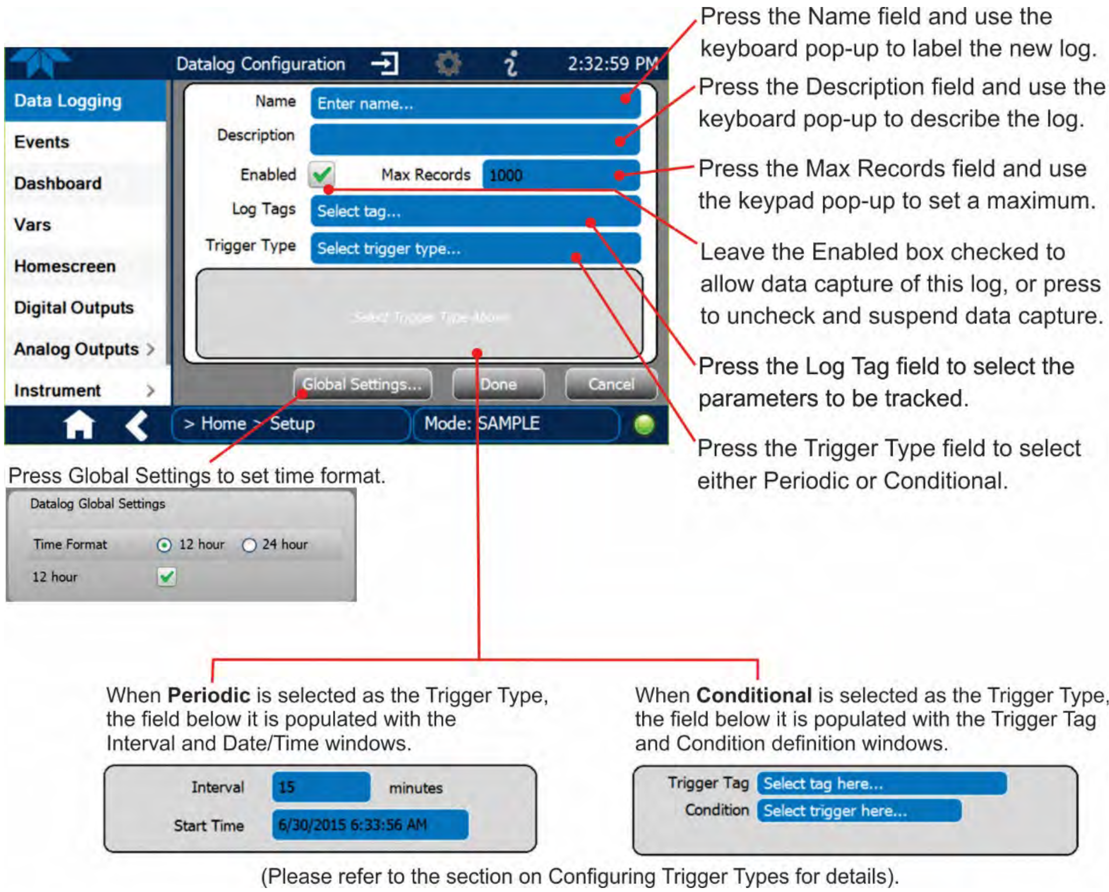


Figure 2-22. Creating a New Data Log

The parameters available in the list of Log Tags include the names of Events configured in the Events page (Section 2.5.2).

2.5.1.1. CONFIGURING TRIGGER TYPES: PERIODIC

The Periodic trigger is a timer-based trigger that is used to log data at a specific time interval. Periodic Trigger requires an interval that is set to number of minutes and a start time that is set to date and clock time.

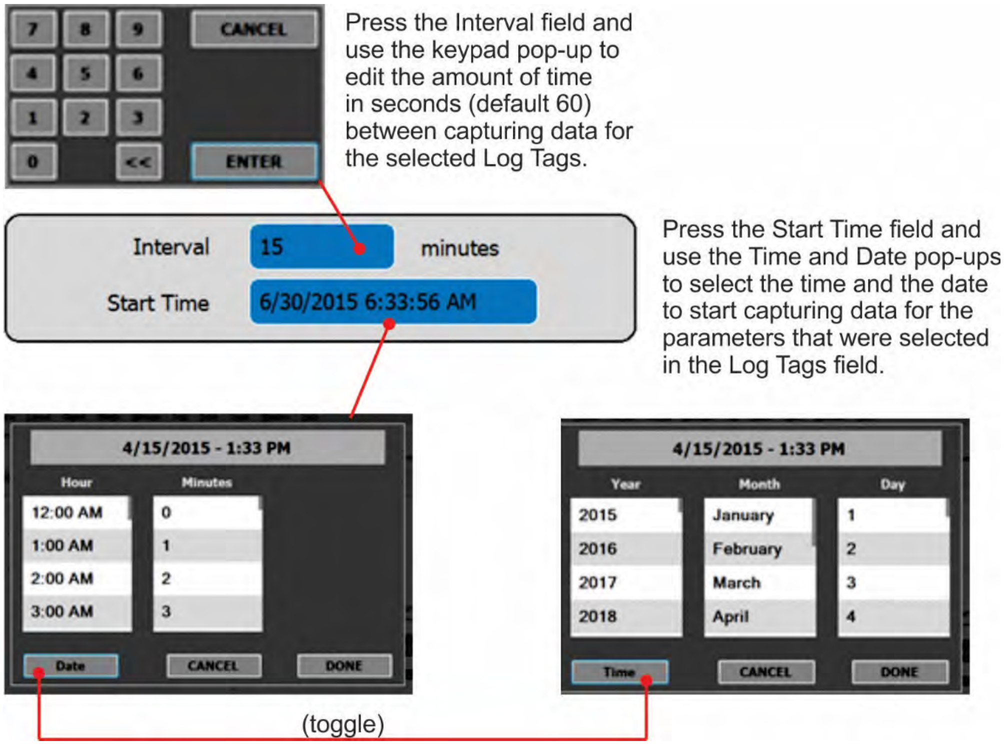


Figure 2-23. Datalog Periodic Trigger Configuration

2.5.1.2. Configuring Trigger Types: Conditional

Conditional Trigger tracks/records data for user-selected parameters that meet specified conditions.

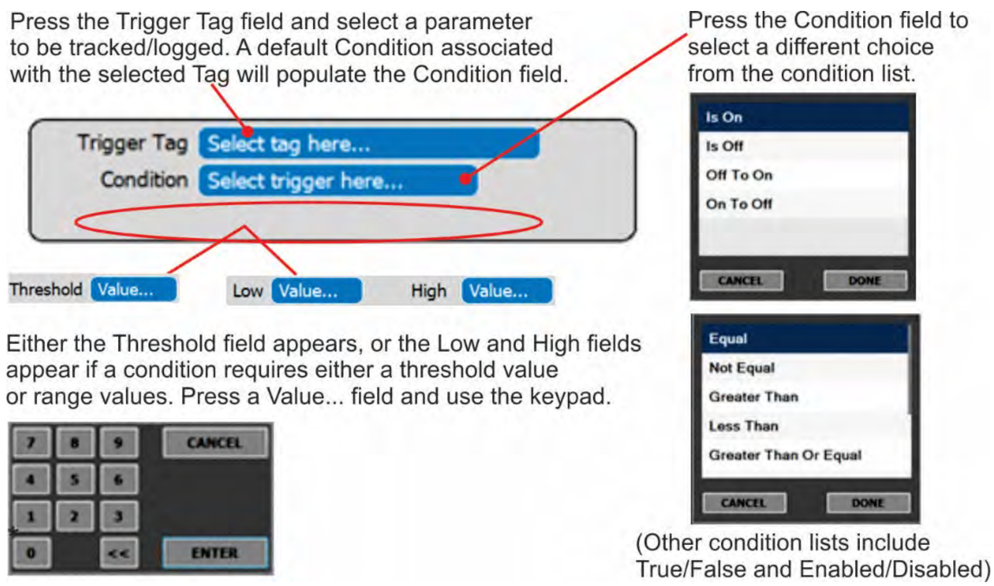


Figure 2-24. Datalog - Conditional Trigger Configuration

2.5.1.3. Downloading DAS (Data Acquisition System) Data

To download DAS data collected by the Datalogger from the instrument to a flash drive, navigate to the Utilities>USB Utilities>DAS Download menu.

1. Insert a flash drive into a front panel USB port and wait for the Status field to Indicates that the drive has been detected; available buttons will be enabled.

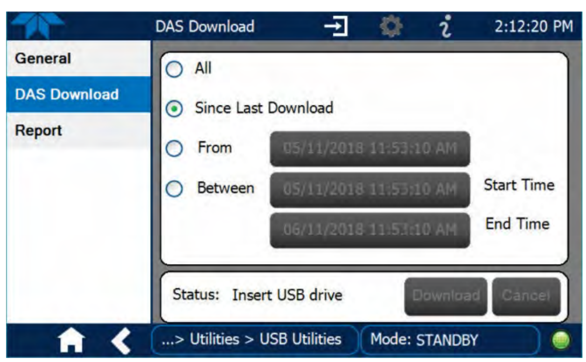


Figure 2-25. DAS Download Page

2. Select all or define a period from which to download the collected data.
3. Press the Download button, and when complete, as indicated in the Status field, press the Done button (changed from "Cancel") and remove the flash drive.

2.5.2. SETUP>EVENTS

Events are occurrences that relate to any operating function and are used to define the conditions that can be set to trigger Alerts (Section 2.4.3). Events can provide diagnostic information about the instrument, typically referred to as “Warnings”, or they can provide other information on instrument functionality, such as concentration alarms. Some Events are standard and not editable while others are user-configurable, described here. Existing Events are listed in the Events page (Figure 2-26) under the Setup menu.

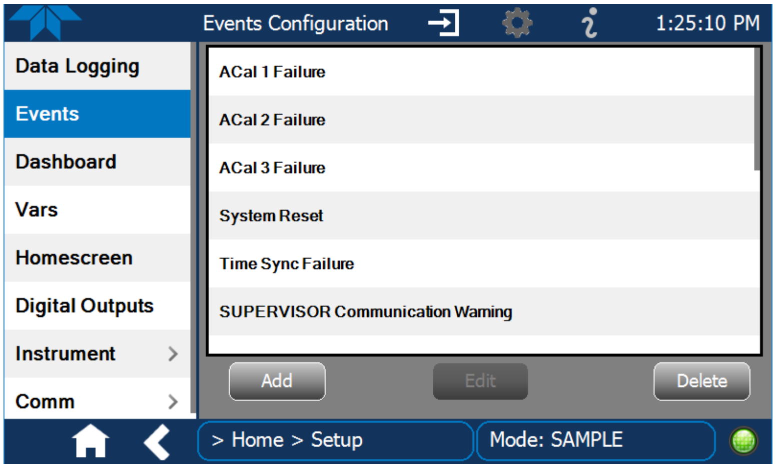


Figure 2-26. Events List

Access the Events Configuration page either from the Active Alerts page (Alerts Menu) by pressing the configuration button, or through the Home>Setup>Events menu (Figure 2-26). Press ADD to create a new Event (refer to Figure 2-27 for details), or select an existing Event to either Edit or Delete it (Figure 2-29).

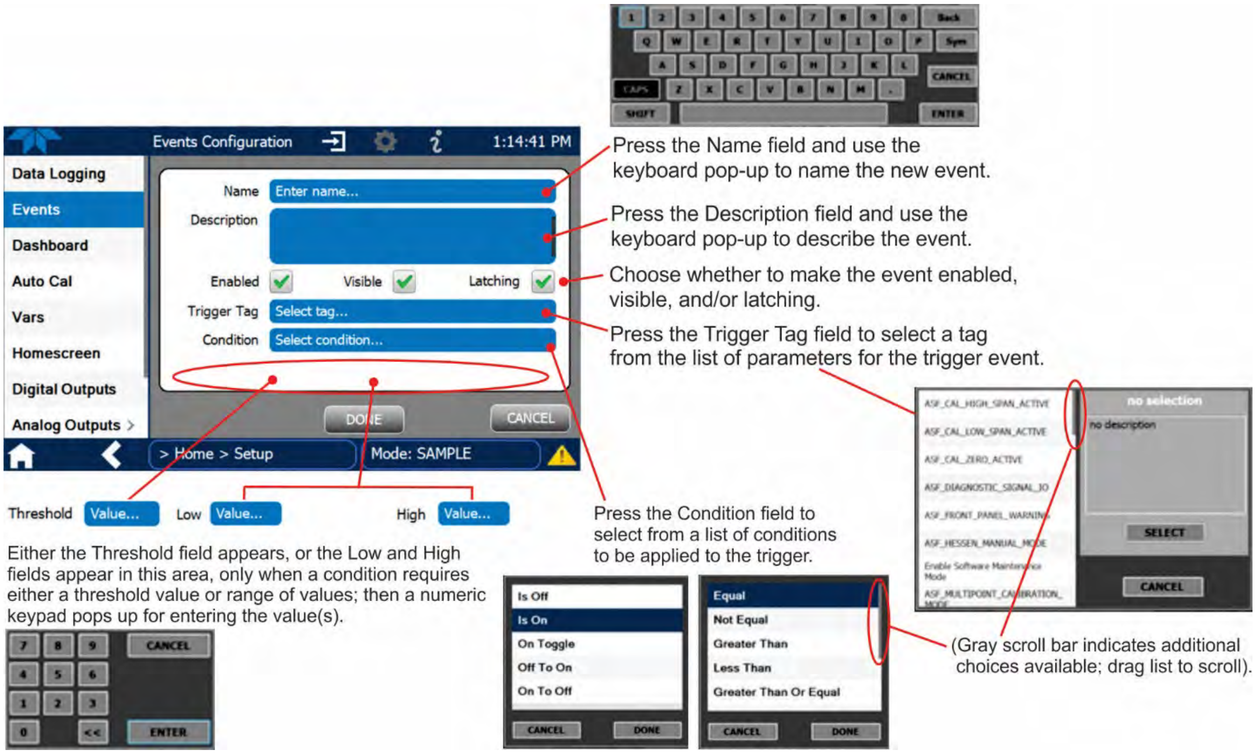


Figure 2-27. Event Configuration

- Enabled ✓ allows the choice of whether to track and record the Event (uncheck this box to “turn off” or deactivate the Event without deleting it). An Event must be enabled in order to use the Visible and the Latching options.
- Visible ✓ allows the choice of whether or not to display the Event in the Alerts page when it is triggered (it will still be recorded and can be viewed in the Utilities>Alerts Log).To use this option, the Event must be enabled.
- Latching ✓ allows the choice of whether or not to keep an Event visible even if the conditions that triggered it were to correct themselves. (Latching requires that the user interact with the Active Alerts screen to manually clear the Alert and internal Event state. Non-latching allows the entry in the Active Alerts screen and the internal Event state to continuously update based on the Event criteria, requiring no user interaction to clear the Alert or Event state).

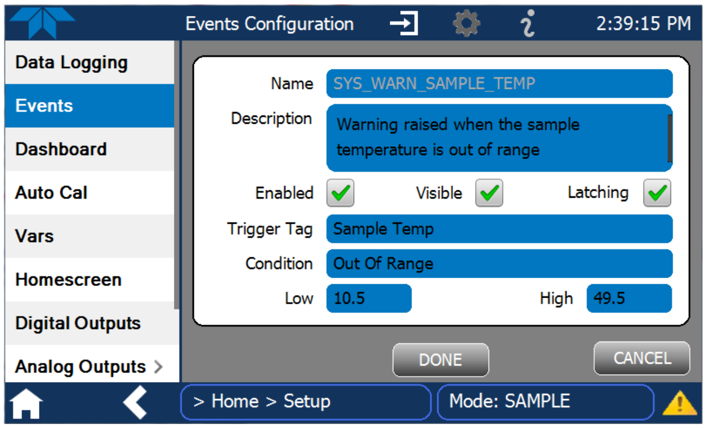


Figure 2-28. Configured Event Sample

2.5.2.1. EDITING OR DELETING EVENTS

Select an Event from the list (Figure 2-26) and press the Edit button to view or edit the details (Figure 2-28), or press the Delete button to delete the Event.

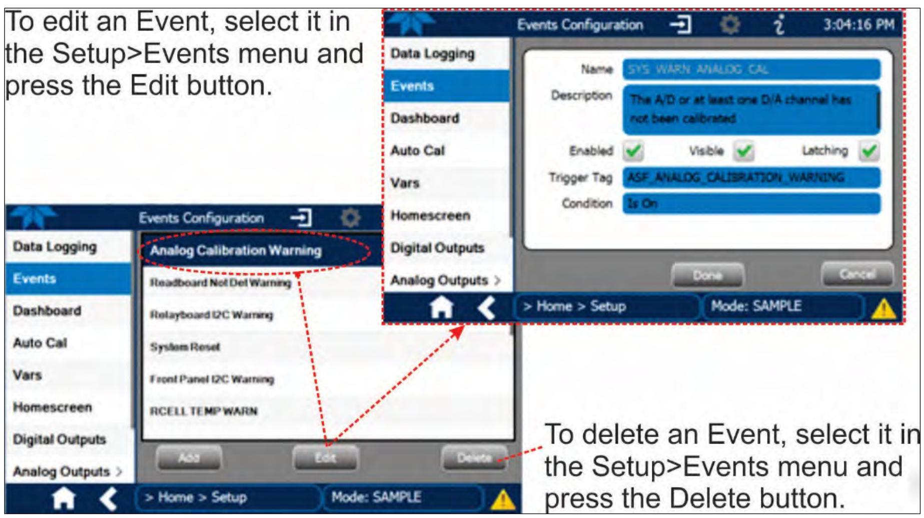


Figure 2-29. Edit or Delete an Event

2.5.2.2. USING EVENTS AS TRIGGERS FOR DATA LOGGING

Events can also be used to create customized triggers for data logging functions. The name entered in the Name field of the Events Configuration page will appear in the list of Log Tags of the Datalog Configuration page. The Data Logger is presented in Section 2.5.1.

2.5.3. SETUP>DASHBOARD

Figure 2-30. Dashboard Display and Configuration

2.5.4. SETUP>AUTOCAL (WITH VALVE OPTION)

Auto Cal is available with installed valve options (see Section 4.3).

2.5.5. SETUP>VARS

Vars are user-adjustable software variables that define operational parameters automatically set by the instrument's firmware. Access the menu to see the list of variables; select a variable to view its description; use the Edit button to change its setting(s).

Table 2-8. List of Variables with Descriptions

VARIABLE	DESCRIPTION
This list includes several of the most common Vars; selecting any Var in the NumaView™ software interface will display its description in the information field to its right. Depending on configuration, some, all, or more of these variables appear in your instrument's Vars menu.	
Background Periodic Report Upload	Allows/disallows uploading of basic functionality reports to a Web services "cloud" for TAPI Technical Support to view. (Frequency can be edited in Setup>Vars>Report Upload Interval).
Conc Precision (or PRIGAS/SECGAS Precision)	Sets the number of significant digits to the right of the decimal point display of concentration and stability values. ("PRIGAS" = primary gas with two or more other gases; "SECGAS" = secondary gas)
Daylight Savings Enable	Enable or disable Daylight Savings Time (also see Setup>Instrument>Date/Time Settings)
Dilution Factor (option)	Sets the instrument to compensate for diluted sample gas, such as in continuous emission monitoring (CEM) where the quality of gas in a smokestack is being tested and the sampling method used to remove the gas from the stack dilutes the gas. Once the degree of dilution is known, this feature allows the user to add an appropriate scaling factor to the analyzer's NO, NO_2 and NOx concentration calculations so that the undiluted values for measurement range and concentration are shown on the instrument's front panel display and reported via the instrument's various outputs. Set the appropriate units of measure (Setup>Vars>User Units). Select the reporting range mode (Setup>Vars>Range Mode) and set the reporting range upper limit (Setup>Analog Output). Ensure that the upper span limit entered for the reporting range is the maximum expected concentration of the undiluted gas. Set the dilution factor as a gain, e.g., a value of 20 means 20 parts diluent and 1 part sample gas (Setup>Vars>Dilution Factor). Calibrate the analyzer; ensure that the calibration span gas is either supplied through the same dilution system as the sample gas or has an appropriately lower actual concentration.
Dynamic Span Enable	Dynamic span automatically adjusts the offsets and slopes of the NO_2 and NO_x response when performing a span point calibration during an AutoCal (Section 4.3).
Dynamic Zero Enable	Dynamic zero automatically adjusts offset and slope of the NO_2 and NO_X response when performing a zero point calibration during an AutoCal (Section 4.3).
Instrument ID	Set unique identifier number for the instrument when it is connected with other instruments on the same Ethernet LAN, or when applying MODBUS protocol.
Measure Mode	Set gas measure mode.
Ozone Lamp Setpoint	(Adjustment is dependent on low Titration Efficiency, Section 4.4).
System Hours	Total system runtime hours
Titration Efficiency	Used for checking or calibrating efficiency of ozone titrating NO (Section 4.4).

2.5.6. SETUP>HOMESCREEN

To select a parameter ("tag") for display in each of the three meters at the bottom of the Home page, navigate to the Homescreen configuration page through either the Setup>Homescreen menu or from Home page using the configuration icon (Figure 2-31).

Figure 2-31. Homescreen Configuration

An orientation to the Homescreen was presented in Section 2.4.1, including Figure 2-14 and Figure 2-15.

2.5.7. SETUP>DIGITAL OUTPUTS (OPTION)

Specify the function of each digital output (connected through the rear panel Digital I/O connector, Figure 2-5) by mapping the outputs to a selection of "Signals" present in the instrument. Create custom "Signals" in the Setup>Events menu (Section 2.5.2). The three Relays can also be connected, and functions assigned.

To map Digital Outputs to Signals, select a pin in the Outputs list (DO1 thru DO5), then make a selection from the Signals list and press the Map button; if/as needed, change the polarity by pressing the Polarity button. Save any changes by pressing the Apply button, or discard the changes by pressing the Home or the back button (a pop-up provides a warning that the changes will be lost, and will prompt for confirmation to apply changes or not). Map the Digital Relays in the same manner.

Navigate to the Utilities>Diagnostics>Digital Outputs menu to change the state (ON/OFF) of individual digital outputs.

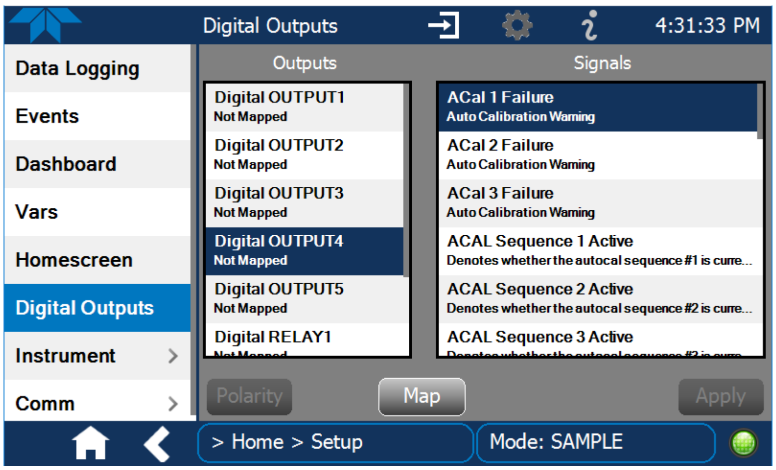


Figure 2-32. Digital Outputs Setup

2.5.8. SETUP>ANALOG OUTPUTS (OPTION)

Map the four user-configurable Analog Outputs to any of a wide variety of "Signals" present in the instrument and customize their respective configurations.

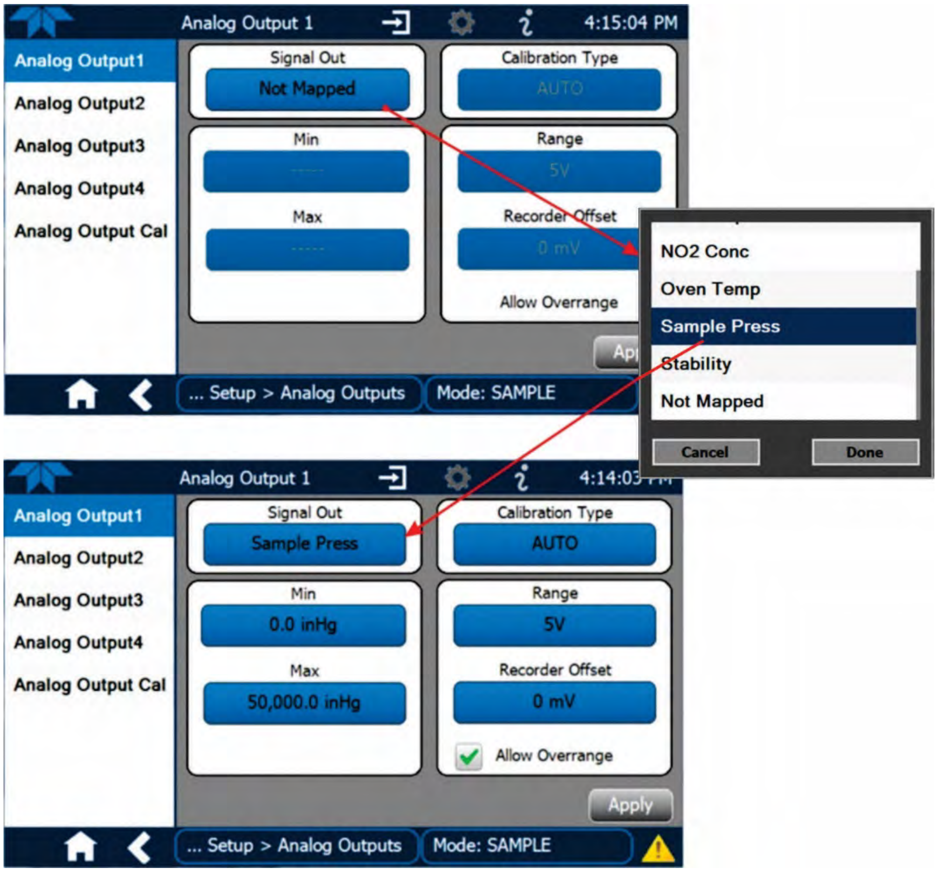


Figure 2-33. Analog Output Option Configuration Example

Refer to Figure 2-33 for the following settings in each of the fields:

- Signal Out: select a Signal for the output.
- Min/Max: edit minimum and maximum values associated with the selected Signal.
- Calibration Type:
  - AUTO for group calibration (Figure 2-34) of the analog outputs (cannot be selected when Current is selected for the Range)
  - MANUAL for individual calibration (Figure 2-35) of analog outputs where manual adjustments can be made (the only calibration type allowed when Current is selected for the Range). See Sections 2.5.8.1 and 2.5.8.2 .
- Range: assign a voltage or select Current (refer to Table 2-9).
- Recorder Offset: add a zero offset for recording slightly negative readings from noise around the zero point.
- Allow Overrange: check to allow a ± 5% over-range; uncheck to disable over-range if the recording device is sensitive to excess voltage or current.

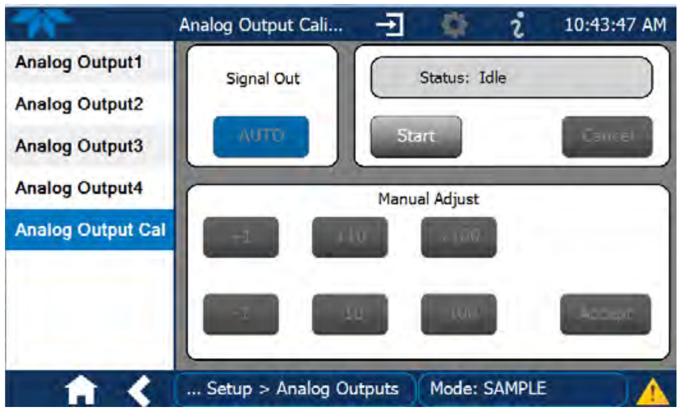


Figure 2-34. Analog Outputs Group Calibration Screen

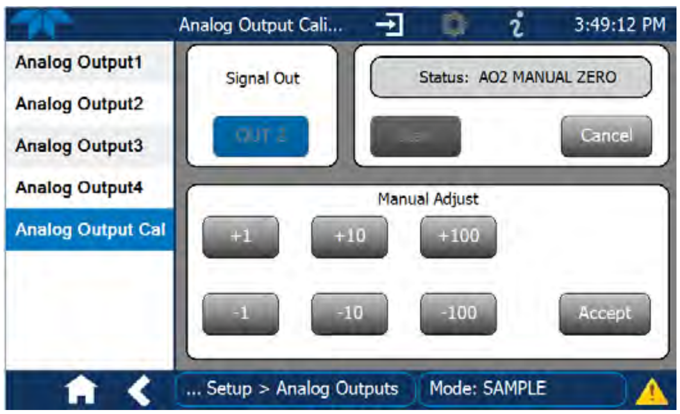


Figure 2-35. Analog Outputs Option Manual Calibration Screen (AOUT2 Example)

Table 2-9. Analog Output Option Voltage/Current Range

RANGE[1]	RANGE SPAN	MINIMUM OUTPUT	MAXIMUM OUTPUT
5V	0-5 VDC	- 1 VDC	6 VDC
10V	0-10 VDC	- 2 VDC	12 VDC
Current	4-20 mA	3 mA	21 mA

[1] Each range is usable from -5% to +5% of the rated span.

For manual calibration adjustments, see Section 2.5.8.1 for voltage and Section 2.5.8.2 for current.

2.5.8.1. Manual Calibration of Voltage Range Analog Outputs Option

It is possible to manually calibrate the voltages by using a voltmeter connected across the output terminals (Figure 2-36) and changing the output signal level when Manual is selected in the Calibration Type field of the Analog Output screen (Figure 2-35).

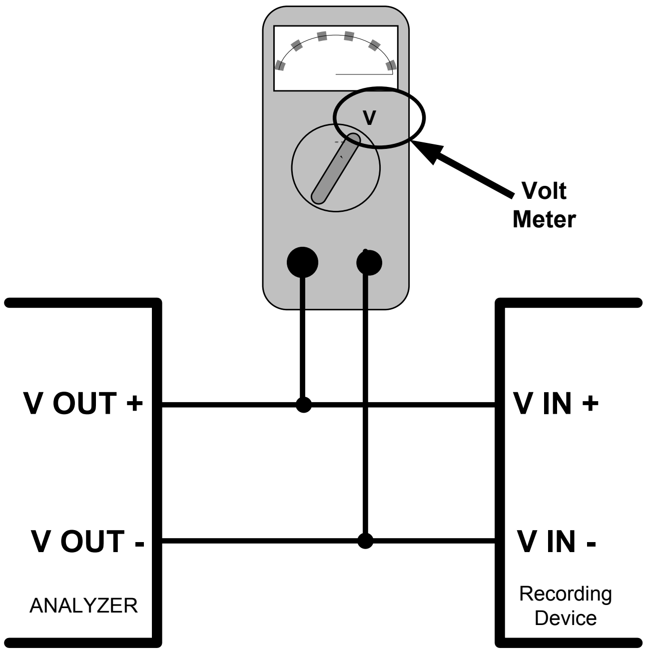


Figure 2-36. Setup for Checking / Calibrating DCV Analog Output Signal Levels

2.5.8.2. Manual Adjustment of Current Range Analog Outputs Option

This option changes the normal DC voltage output to a 4-20 milliamp signal. Adjusting the signal zero and span levels of the current loop output is done by raising or lowering the voltage output of the D-to-A converter circuitry. This raises or lowers the signal level produced by the current loop option circuitry.

The software allows this adjustment to be made in 100, 10 or 1 count increments. Since the exact amount by which the current signal is changed per D-to-A count varies from output-to-output and instrument-to-instrument, you will need to measure the change in the signal levels with a separate, current meter placed in series with the output circuit. See Figure 2-4 for pin assignments and diagram of the analog output connector.

CAUTION!

Do not exceed 60 V peak voltage between current loop outputs and instrument ground.

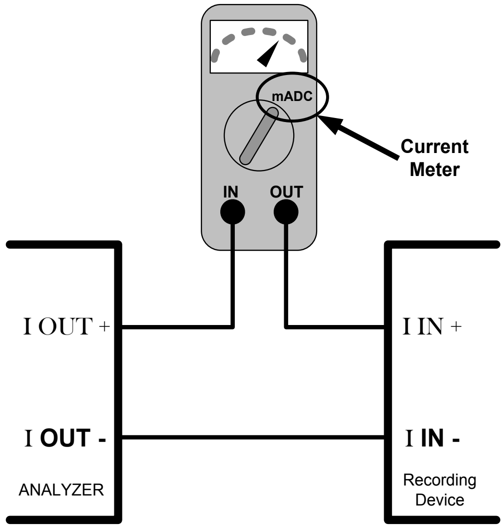


Figure 2-37. Setup for Checking / Calibrating Current Output Signal Levels

An alternate method for measuring the output of the Current Loop converter is to connect a 250 ohm ±1% resistor across the current loop output in lieu of the current meter (see Figure 2-4 for pin assignments and diagram of the analog output connector). This allows the use of a voltmeter connected across the resistor to measure converter output as VDC or mVDC.

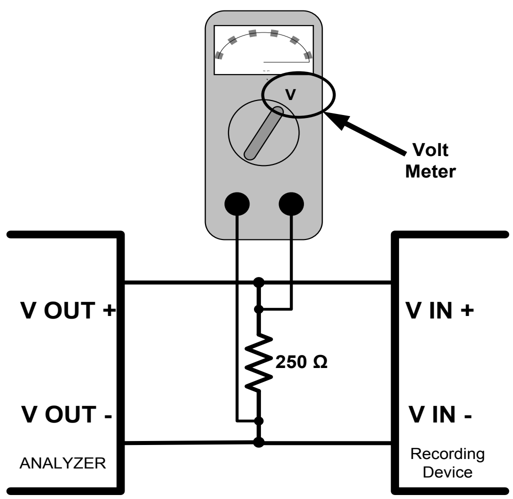


Figure 2-38. Alternative Setup Using 250Ω Resistor for Checking Current Output Signal Levels

In this case, follow the procedure above but adjust the output for the following values:

Table 2-10. Current Loop Output Check

% FS	Voltage across Resistor for 4-20 mA
0	1000 mVDC
100	5000 mVDC

2.5.9. SETUP>INSTRUMENT

As presented in Table 2-11, view product and system information and network settings, edit network settings, and perform certain maintenance tasks.

Table 2-11. Setup>Instrument Menu

MENU	DESCRIPTION
Product Info	View Model, Part, and Serial Numbers and Package and Driver Versions, and options information.
System Info	View Windows and RAM information.
Network Settings	View the network settings (configurable through the Setup>Comm>Network Settings menu).
Date/Time Settings	Adjust date, hour, and minutes, select a time zone*, and set the system clock to automatically adjust for Daylight Savings Time or not. (Also see Setup>Vars>Daylight Savings Enable). *Time Zone change requires a special procedure; see Maintenance Section 5.5.
NTP Time Settings	Configure Network Time Protocol settings for clock synchronization.
Language	Select an available language.
Remote Update	When an instrument is connected to a network that is connected to the Internet, follow the instructions on this Remote Update page to check for and activate software/firmware updates. (Also refer to Section 5.3).

2.5.10. SETUP>COMM (COMMUNICATIONS)

This menu is for specifying the various communications configurations.

2.5.10.1. COM1

Configure the instrument's COM port to operate in modes listed in Table 2-12.

Table 2-12. COM1 Setup

MODE	DESCRIPTION
Baud Rate	Set the baud rate.
Command Prompt Display	Enable/disable a command prompt to be displayed when in terminal mode.
Data Bits	Set the data bits to 7 or 8 (typically set in conjunction with Parity and Stop bits).
Echo and Line Editing	Enable/disable character echoing and line editing.
Handshaking Mode	Choose SOFTWARE handshaking for data flow control (do NOT use SOFTWARE handshaking mode when using MODBUS RTU for Protocol mode; select only HARDWARE or OFF for MODBUS RTU), or HARDWARE for CTS/RTS style hardwired transmission handshaking. (This style of data transmission handshaking is commonly used with modems or terminal emulation protocols). Or choose to turn OFF handshaking.
Hardware Error Checking	Enable/disable hardware error checking.
Hardware FIFO	Enable/disable the hardware First In – First Out (FIFO) for improving data transfer rate for that COM port.
Modem Connection	Select either a modem connection or a direct cable connection.

MODE	DESCRIPTION
Modem Init String	Input an initialization string to enable the modem to communicate.
Parity	Select odd, or even, or no parity (typically set in conjunction with Data Bits and Stop Bits).
Protocol	If selecting a MODBUS protocol, see Handshaking Mode notes, this table; MODBUS Registers are presented in Appendix A, this manual. Also see www.modbus.org.
Quiet Mode	Enable/disable Quiet mode, which suppresses any feedback from the analyzer (such as warning messages) to the remote device and is typically used when the port is communicating with a computer program where such intermittent messages might cause communication problems. Such feedback is still available, but a command must be issued to receive them.
Security	Enable/disable the requirement for a password for this serial port to respond. The only command that is active is the request-for-help command, **? CR**.
Stop bits	Select either 0 or 1 stop bit (typically set in conjunction with Parity and Data bits).

2.5.10.2. TCP Port1

TCP Port1 allows choosing whether or not to display the command prompt, editing the Port 1 number for defining the terminal control port by which terminal emulation software addresses the instrument, such as Internet or NumaView™ Remote software, and enabling or disabling security on this port.

2.5.10.3. TCP Port2

TCP Port2 is configured with the port number for MODBUS (Registers provided in Appendix A).

2.5.10.4. Network Settings

The Setup>Comm>Network Settings menu is for Ethernet configuration. The address settings default to automatic configuration by Dynamic Host Configuration Protocol (DHCP). Most users will want to configure the instrument with a static IP address: click the Static radio button to manually assign a static IP address (consult your network administrator and see Table 2-13 for information).

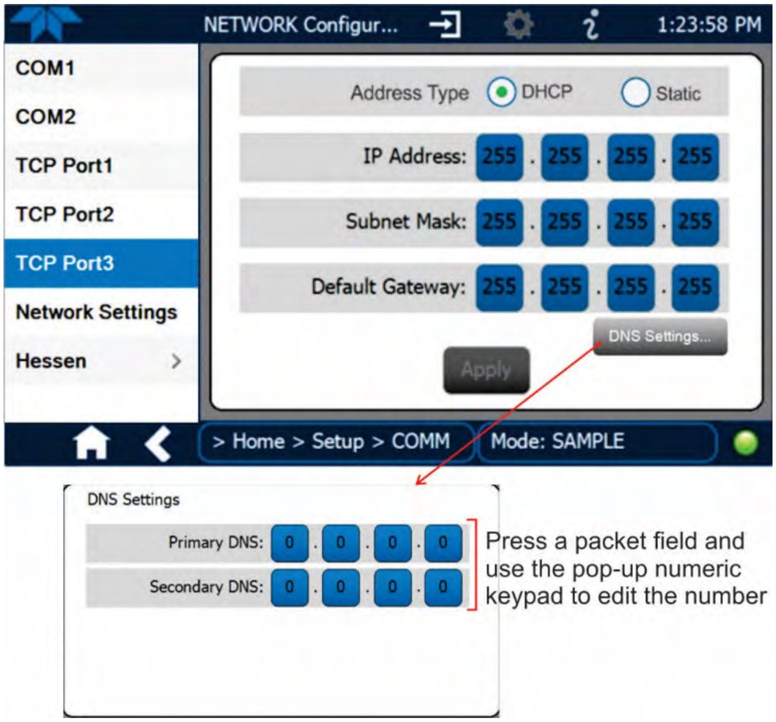


Figure 2-39. Communications Configuration, Network Settings

Table 2-13. LAN/Ethernet Configuration Properties

PROPERTY	DESCRIPTION
IP address	A string of four packets of 1 to 3 numbers each (e.g. 192.168.76.55.) is the internet protocol address of the instrument itself.
Subnet Mask	A string of four packets of 1 to 3 numbers each (e.g. 255.255.252.0) number that masks an IP address, and divides the IP address into network address and host address and identifies the LAN to which the device is connected. All addressable devices and computers on a LAN must have the same subnet mask. Any transmissions sent to devices with different subnets are assumed to be outside of the LAN and are routed through the gateway computer onto the Internet.
Default Gateway	A string of numbers very similar to the Instrument IP address (e.g. 192.168.76.1.) that is the address of the computer used by your LAN and serves as a router to access the Internet or another network.

2.6. TRANSFERRING CONFIGURATION TO OTHER INSTRUMENTS

Once an instrument is configured, the same configuration can be copied to other instruments of the same Model. This encompasses essentially anything the user can configure and does not apply to instrument-specific settings such as those that are configured at the factory for calibration.

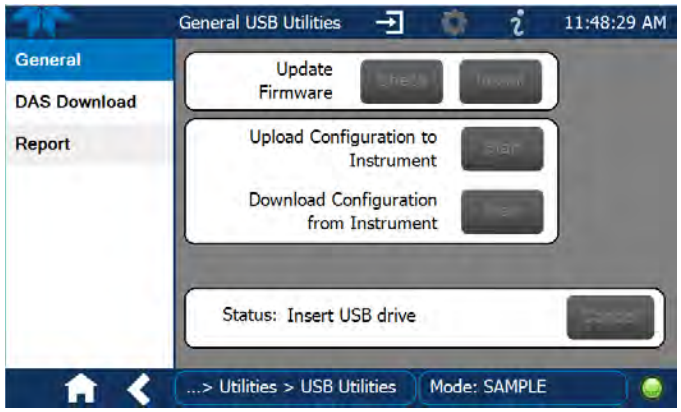


Figure 2-40. Configuration Transfer

1. In the source instrument, go to the Home>Utilities>USB Utilities>General page.
2. Insert a flash drive into either of the two front panel USB ports.
3. When the Status field Indicates that the USB drive has been detected, press the “Download Configuration from Instrument” Start button.
4. When the Status field Indicates that the download is complete, remove the flash drive.
5. In the target instrument, go to the Home>Utilities>USB Utilities>General page.
6. Insert a flash drive into either of the two front panel USB ports.
7. When the Status field Indicates that the USB drive has been detected, press the “Upload Configuration to Instrument” Start button.
8. When the Status field Indicates that the upload is complete, remove the flash drive.

3. COMMUNICATIONS AND REMOTE OPERATION

This instrument's rear panel connections include an Ethernet port and a serial communications port. Connection instructions were provided in Section 2.3.1.4. Configuration information was provided in Section 2.5.10.

Data acquisition is set up through the Datalogger (Section 2.5.1).

3.1. SERIAL COMMUNICATION

The rear panel COM port operates on the RS-232 protocol (default configuration is DCE RS-232), or it can be configured for DTE RS-232 or for half-duplex RS-485 operation (Section 2.3.1.4).

Referring to Table 2-12, use the SETUP>COMM menu to view/edit the communications settings for the COM port.

3.2. ETHERNET

When using the Ethernet interface, the analyzer can be connected to any Ethernet network via low-cost network hubs, switches or routers. The interface operates as a standard TCP/IP device on port 3000. This allows a remote computer to connect through the network to the analyzer using NumaView™ Remote, terminal emulators or other programs.

The Ethernet connector has two LEDs that are on the connector itself, indicating its current operating status.

Table 3-1. Ethernet Status Indicators

LED	FUNCTION
green (link)	On when connection to the LAN is valid.
amber (activity)	Flickers during any activity on the LAN.

The analyzer is shipped with DHCP enabled by default. This allows the instrument to be connected to a network or router with a DHCP server; however, it should be configured with a Static IP address as soon as practical. See Section 2.5.10.4 for configuration details.

3.3. NUMAVIEW™ REMOTE

For remote operation and data capture through an Ethernet connection, please refer to the NumaView™ Remote Software User Guide, PN 08492, available on our website.

4. CALIBRATION

This section is organized into subsections as follows:

SECTION 4.1 – Important Precalibration Information: contains important information you should know before calibrating the instrument.

SECTION 4.2 – Calibration Procedures: describes the procedure for manually checking calibration and performing actual calibration of the instrument.

SECTION 4.3 – Automatic Zero/Span Cal/Check (Auto Cal): describes the procedure for using the AutoCal feature to check calibration or to calibrate the instrument. (The AutoCal feature requires that either the zero/span valve option or the internal span gas generator option be installed and operating).

SECTION 4.4 – Titration Efficiency (TE) Check/Calibration: describes corrections made for titration effects.

SECTION 4.5 – EPA Protocol Calibration: provides links to the US EPA website for references regarding calibration with EPA protocols.

4.1. IMPORTANT PRECALIBRATION INFORMATION

Note	**A start-up period of 4-5 hours is recommended prior to calibrating the analyzer.**

4.1.1. CALIBRATION REQUIREMENTS

The following equipment, supplies, and expendables are required for calibration:

- Zero Air Generator (e.g., T701)
- Span gas source
- Gas lines - all gas line materials should be stainless steel or Teflon-type (PTFE or FEP).
- High-concentration NO_2 gas transported over long distances may require stainless steel lines to avoid oxidation of NO_2 due to the possibility of O_2 diffusing into the tubing.

Optional equipment:

Calibrator with photometer option (e.g., T700U) for use with NO and GPT to span the analyzer.

A recording device such as a strip-chart recorder and/or data logger.

For electronic documentation, the internal data acquisition system (DAS) can be used by configuring the Datalogger through the Setup>Data Logging menu; Section 2.5.1).

The method for performing an initial calibration for the analyzer differs between the standard instrument and those with options.

- See Section 4.2.1 for instructions for initial calibration of the analyzer in its base configuration.
- See Section 4.2.2 for information regarding setup and calibration of the analyzer with Z/S Valve options.

Note **Zero air and span gases must be supplied at twice the instrument's specified gas flow rate.**

4.1.2. ZERO AIR

Zero air or zero calibration gas is similar in chemical composition to the measured medium but without the gas to be measured by the analyzer. A zero generator, such as the Teledyne API Model T701, can be used.

4.1.3. CALIBRATION (SPAN) GAS

NO_2 cylinder Calibration gas is diluted, using a T700 calibrator, to match the chemical composition of the type of gas being measured at near full scale of the desired reporting range. Thus, it is recommended that the span gas be of a concentration equal to 80% of the measurement range for your application.

Alternatively, if a calibrator is available that contains a trusted source of stable ozone, e.g., Teledyne API Model T700U with certified photometer, it is possible to use that O_3 output directly to obtain the NO_2 concentration using GPT.

CAUTION!

If the presence of ozone is detected at any time, power down the instrument and contact Teledyne API Technical Support as soon as possible:

+1 800-324-5190 or email: api-techsupport@teledyne.com

4.1.4. SPAN GAS FOR MULTIPOINT CALIBRATION

Some applications, such as EPA monitoring, require a multipoint calibration where span gases of different concentrations are needed. We recommend using an NO_2 gas cylinder of higher concentration combined with a gas dilution calibrator such as the Teledyne API Model T700. Calibrators mix high concentration span gas with zero air to accurately produce span gas of the desired concentration. Linearity profiles can be automated with these models and run unattended overnight.

If a dynamic dilution system is used to dilute high concentration gas standards to low, ambient concentrations, ensure that the NO_2 concentration of the reference gas matches the dilution range of the calibrator. (Section 2.5.5 contains information about the dilution option).

Choose the NO_2 gas concentration so that the dynamic dilution system operates in its mid-range and not at the extremes of its dilution capabilities.

EXAMPLE:

- A dilution calibrator with 10-10000 dilution ratio will not be able to accurately dilute a 5000 ppm NO_2 gas to a final concentration of 500 ppb, as this would operate at the very extreme dilution setting.
- A 100 ppm NO_2 gas in nitrogen is much more suitable to calibrate the analyzer (dilution ratio of 200, in the mid-range of the system's capabilities).

4.1.5. NO_2 PERMEATION TUBES

Teledyne API offers an optional internal span gas module that utilizes an NO_2 permeation tube as a span gas source. The accuracy of these devices is only about ±5%. Whereas this may be sufficient for quick, daily calibration checks, we recommend using certified NO_2 gases for accurate calibration.

CAUTION!

Insufficient gas flow allows gas to build up to levels that will contaminate the instrument or present a safety hazard to personnel.

In units with a permeation tube installed, either the tube must be removed and stored in a sealed container (use original container that tube was shipped in) during periods of non-operation, or vacuum pump must be connected and powered on to maintain constant gas flow though the analyzer at all times.

(See Section 5.6.4 for removal instructions).

4.1.6. DATA RECORDING DEVICES

A strip chart recorder, data acquisition system or digital data acquisition system should be used to record data from either the Ethernet, serial or analog outputs.

- If analog readings are used, the response of the recording system should be checked against a NIST traceable voltage source or meter.
- Data recording devices should be capable of bi-polar operation so that negative readings can be recorded.

For electronic data recording, the analyzers provide an internal data logger, which is configured through the Setup>Data Logger menu (Section 2.5.1).

NumaView™ Remote is a remote control program, which is also available as a convenient and powerful tool for data viewing and handling, download, storage, quick check and plotting.

4.2. CALIBRATION PROCEDURES

Check that the pneumatic connections for the specific instrument configuration are as instructed in Section 2.3.2. Calibration procedures include setting the expected span gas concentration (see Note below).

Verify User Units setting and Titration Efficiency (TE) value:

- User Units (unit of Measure): PPB
- TE is 96% or greater (check Titrate Eff in Dashboard; if less than .96, adjust in Setup>Vars – see Section 4.4. No adjustment needed if ≥ .96).

Then perform the calibration:

- Perform a Zero calibration using zero air on both NO_2 & NOx channels.
- Perform a Span calibration on both the NO_2 & NOx channels using a known concentration of NO_2 span gas.
- Perform the Titration Efficiency (TE) check using a known concentration of NO span gas. No adjustment of TE value is required if the efficiency is good.

Note — **The span gas concentration should be 80% of range of concentration values likely to be encountered in your application.**

To calibrate or to perform a calibration check for basic configuration instruments, see Section 4.2.1.

To calibrate or to perform a calibration check for instruments with valve options, see Section 4.2.2.

To perform a calibration check for instruments with the internal span gas generator, see Section 4.3.

4.2.1. CALIBRATION AND CHECK PROCEDURES FOR BASIC CONFIGURATION

Although this section uses the Calibration menu for both calibration check and actual calibration, a check does not require the Calibration menu. Instead, while in Home page, simply flow the zero air or the NO_2 span gas through the Sample port, and check the reading after the Stability falls below 1.0 PPB (either in the gas graph or in the Dashboard).

Otherwise, follow the steps presented in Sections 4.2.1.1 and 4.2.1.2.

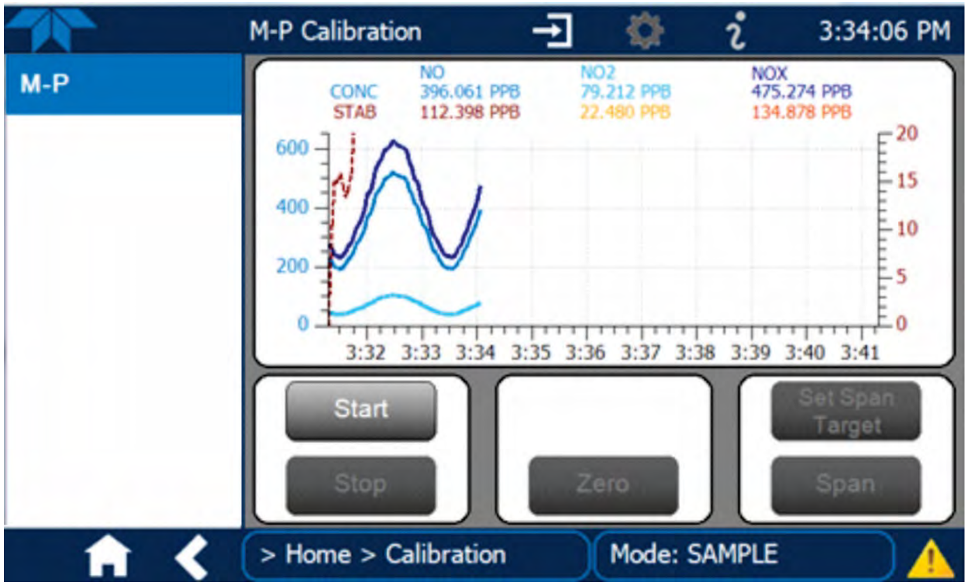


Figure 4-1. Multi-Point Calibration Page

4.2.1.1. Zero Calibration Check and Actual Calibration

1. Go to the Calibration>M-P menu.
2. Input Zero air through the Sample port and press the Start button.
3. Either check or calibrate as follows:

CHECK ONLY:

a. Wait for reading to stabilize.
b. Press Stop and check the reading.

ACTUAL CALIBRATION:

a. Press the Zero button.
b. Press Stop and check the reading.

4.2.1.2. Span Calibration Check and Actual Calibration

1. While still in the Calibration>M-P menu, input NO_2 Span gas through the Sample port and press the Start button.
2. Either check or calibrate as follows:

CHECK ONLY:

a. Wait to reach stability, then press Stop.
b. Record the reading(s).

ACTUAL CALIBRATION:

a. Press the Set Span Target button and enter the NO_2 and NOx concentrations.
b. Verify the concentration reading is the same as the NO_2 concentration being supplied.
c. If correct, wait to reach stability, then press the Span button.
d. In the Cal Result window, press OK.

3. Press the Stop button and return to Home screen.

4. In the Dashboard, check and record the Slope(s) and the Offset(s).

4.2.2. CALIBRATION AND CHECK PROCEDURES WITH VALVE OPTIONS INSTALLED

Figure 4-2. Zero and Span Calibration Screens

Follow the instructions in Section 4.2.1, except instead of the M-P menu, go to the Calibration>Zero menu for Zero cal and to the Calibration>Span menu for NO_2 Span cal.

4.2.2.1. USE OF ZERO/SPAN VALVE WITH DIGITAL EXPANSION BOARD OPTION

Digital inputs are available for controlling calibration and calibration checks , when the Digital I/O Board option is installed. Instructions for setup and use of this option are outlined in Section 2.3.1.3.

When the Digital Inputs are activated for at least 5 seconds, the instrument switches into zero, low span or high span mode and the internal zero/span valves will be automatically switched to the appropriate configuration.

- The remote calibration Digital Inputs may be activated in any order.
- It is recommended that the Digital Inputs remain closed for at least 10 minutes to establish a reliable reading.
- The instrument will stay in the selected mode for as long as the Input remains closed.

If Digital Inputs are being used in conjunction with the analyzer's AutoCal (see Section 4.3) feature and the AutoCal attribute "Calibrate" is enabled (selection box is checked), the analyzer will not recalibrate the analyzer UNTIL the Input is opened. At this point, the new calibration values will be recorded before the instrument returns to SAMPLE mode.

If the AutoCal attribute "Calibrate" is disabled (selection box is unchecked), the instrument will return to SAMPLE mode, leaving the instrument's internal calibration variables unchanged.

4.3. AUTOMATIC ZERO/SPAN CAL/CHECK (AUTO CAL)

The Auto Cal feature allows unattended periodic operation of the ZERO/SPAN valve options by using the instrument's internal time of day clock. Auto Cal operates by executing preprogrammed calibrations or calibration checks set up by the user to initiate the various calibration states of the analyzer and to open and close valves appropriately. It is possible to set up and run up to three separate preprogrammed calibrations or calibration checks (labeled # **1**, **2** and **3**). Each calibration or check can operate in one of three modes (Zero, Low or High), or be disabled.

Table 4-1 and Table 4-2 show how to set up the operating states of each calibration or check, and Table 4-3 shows how to program the execution of each.

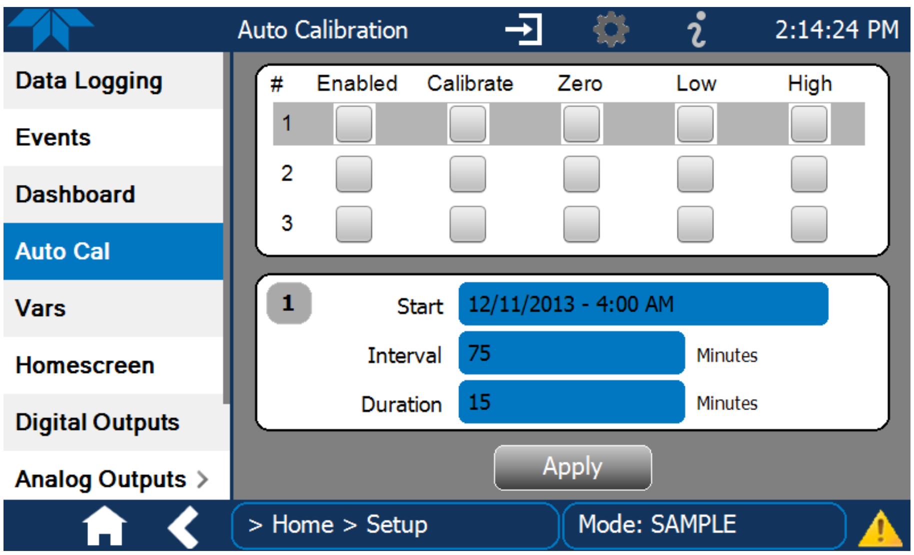


Figure 4-3. Auto Cal Page

Table 4-1. AUTO CAL States

MODE NAME	ACTION
Enabled	☑ enables the sequence. ☐ disables the sequence.
Calibrate	☑ enables an actual calibration when the Enabled box is also ☑. ☐ allows a calibration check when the Enabled box is also ☑.
Zero	☑ causes the sequence to perform a Zero calibration when both the Calibrate and Enabled boxes are also ☑. ☑ causes a Zero check when the Enabled box is also ☑ and the Calibrate box is unchecked (☐). ☐ disables Zero calibration and check
Low	☑ causes the sequence to perform a Low Span calibration when both the Calibrate and Enabled boxes are also ☑. ☑ causes a Low Span check when the Enabled box is also ☑ and the Calibrate box is unchecked (☐). ☐ disables Low Span calibration and check
High	☑ causes the sequence to perform a High Span concentration calibration when both the Calibrate and Enabled boxes are also ☑. ☑ causes a High Span check when the Enabled box is also ☑ and the Calibrate box is unchecked (☐). ☐ disables the High Span calibration and check.

Table 4-2 shows how the selection boxes would be enabled/disabled for calibration checks and calibrations.

Table 4-2. Auto Cal Setup Combinations

MODE	ACTION	STATE				
		Enabled	Calibrate	Zero	Low	High
Zero	Check	☑	☐	☑	☐	☐
	Calibrate	☑	☑	☑	☐	☐
Low	Check	☑	☐	☐	☑	☐
	Calibrate	☑	☑	☐	☑	☐
High	Check	☑	☐	☐	☐	☑
	Calibrate	☑	☑	☐	☐	☑
Zero Low High	Check	☑	☐	☑	☑	☑
	Calibrate	☑	☑	☑	☑	☑

For each sequence, there are four parameters that control operational details: Date, Time (both in the Start field), Interval, and Duration, as presented in Table 4-3.

Table 4-3. Auto Cal Programming Sequence Execution

ATTRIBUTE	ACTION
Start	When the Enabled box is "on" ✓, the Sequence (identified by its number) begins on the date and time shown in the configurable Start field. (Click the field for the pop-up window and toggle between the Time (Hour/Minutes) and the Date (Year/Month/Day) attributes to edit as needed).
Interval	Number of minutes to skip between each Sequence execution. (Click the field to input the number of minutes in the pop-up window).
Duration	Number of minutes that each Sequence execution is to run. (Click the field to input the number of minutes in the pop-up window).

Important

IMPACT ON READINGS OR DATA

- **The programmed STARTING_TIME must be a minimum of 5 minutes later than the real time clock for setting real time clock (Setup>Instrument, Section 2.5.7).**
- **Avoid setting two or more sequences at the same time of the day.**
- **Any new sequence that is initiated whether from a timer, the COM ports or the contact closure inputs will override any sequence that is in progress.**
- **It is recommended that calibrations be performed using external sources of Zero Air and Span Gas whose accuracy is traceable to EPA standards.**

4.4. TITRATION EFFICIENCY (TE) CHECK/CALIBRATION

The efficiency at which the O_3 titrates NO into NO_2 in the sample gas can change over time, thereby affecting the accuracy of the instrument's NOx measurement. To compensate for this and maintain accuracy, the firmware includes a Titration Efficiency (TE) gain factor that is used to adjust the calculated NO gas concentration. This gain factor is stored in the analyzer's memory.

The method is to deliver a known concentration of NO span gas, having first calibrated the instrument with NO_2, typically 80%-90% of the desired range, and after the instrument stabilizes, perform a TE adjustment in the Vars menu, if required (Setup>Vars>Titrate Eff). This adjusts the calculated NO concentration, which is then added to the measured NO_2 concentration to calculate the corrected NO_X value.

4.5. EPA PROTOCOL CALIBRATION

When running this instrument for U.S. EPA compliance, always calibrate prior to use, adhering to the EPA designation requirements for this instrument. (The official List of Designated Reference and Equivalent Methods is published in the U.S. Federal Register: http://www3.epa.gov/ttn/amtic/criteria.html; this List specifies the settings and configurations for EPA calibration protocol). Pay strict attention to the built-in warning features, periodic inspection, regular zero/span checks, regular test parameter evaluation for predictive diagnostics and data analysis, and routine maintenance. Any instrument(s) supplying the zero air and span calibration gasses used must themselves be calibrated, and that calibration must be traceable to an EPA/NIST primary standard.

Comply with Code of Federal Regulations, Title 40 (downloadable from the U.S. Government Publishing Office at http://www.gpo.gov/fdsys/) and with Quality Assurance Guidance documents (available on the EPA website: http://www3.epa.gov/ttn/amtic/qalist.html). Give special attention to specific regulations regarding the use and operation of ambient NO_X analyzers using Cavity Attenuated Phase Shift Spectroscopy method.

5. MAINTENANCE AND SERVICE

Although the Model N500 analyzer requires little service, a few simple procedures should be performed regularly to ensure that it continues to operate accurately and reliably over its lifetime. In general, the exterior can be wiped down with a lightly damp cloth. Service and troubleshooting are covered in Section 5.7.

ATTENTION

COULD DAMAGE INSTRUMENT AND VOID WARRANTY
Avoid spraying anything directly onto any part of the analyzer.

5.1. MAINTENANCE SCHEDULE

Table 5-1 shows a typical maintenance schedule. The actual frequency of performing these procedures can vary depending on the operating environment. Additionally, in some cases, there are local regulations or standards that also need to be considered.

In certain environments (e.g., dusty, very high ambient pollutant levels) some maintenance procedures may need to be performed more often than shown.

WARNING – ELECTRICAL SHOCK HAZARD

Disconnect power before performing any of the following operations that require entry into the interior of the analyzer.

CAUTION – QUALIFIED PERSONNEL

These maintenance procedures must be performed by qualified technicians only.

Important

IMPACT ON READINGS OR DATA

A span and zero calibration check (see CAL CHECK REQ'D Column of Table 5-1) must be performed following some of the maintenance procedures listed herein. To perform a CHECK of the instrument's Zero or Span Calibration, refer to Sections 4.2.1.1 and 4.2.1.2, respectively.

DO NOT press the Zero or Span buttons at the end of each operation (actual calibration), as this will reset the stored values for OFFSET and SLOPE and alter the instrument's calibration.

Alternatively, use the Auto Cal feature described in Section 4.3 with the CALIBRATE attribute set to OFF (not enabled).

Table 5-1. Maintenance Schedule

ITEM	ACTION	FREQ	CAL CHECK REQ'D	DATE PERFORMED									
Dashboard functions	Review and evaluate	Weekly	No										
Zero/span check	Evaluate offset and slope	Weekly	No										
Zero/span calibration	Zero and span calibration	Every 3 months	Yes										
Sample filter	Change sample filter	Annually (may need more frequently in a high dust load environment)	No										
AREF filter assembly	Change	Annually	Yes										
Spectrometer mirrors	Contact Technical Support	As necessary due to excessive Measured Loss	Yes										
Sample conditioner filter assembly	Change	Only if necessary (contact Technical Support)	Yes										
Pneumatic sub-system	Check for leaks in gas flow paths	Annually or after repairs involving pneumatics	Yes, if a leak is repaired										
Internal Pump	Replace	Measured Flow less than 800 cm^3/min	Yes										

5.2. PREDICTIVE DIAGNOSTICS

Predictive diagnostic functions, including failure warnings and alarms built into the analyzer's firmware, aid in determining whether and when repairs are necessary.

Dashboard Functions can also be used to predict failures by looking at how their values change over time, compared to the values recorded on the printed record of the *Final Test and Validation Data Sheet*. The internal data logger is a convenient way to record and track these changes (set up through the Data Logger, Section 2.5.1). Use NumaView™ Remote to download and review this data from a remote location.

The following table, checked weekly, can be used as a basis for taking action as these values change with time.

Table 5-2. Predictive Uses for Dashboard Functions

FUNCTION	EXPECTED	ACTUAL	INTERPRETATION & ACTION
Cell Press (pressure)	Constant within atmospheric changes	Fluctuating	Developing leak in pneumatic system. Check for leaks.
		Slowly increasing	Developing leak in pneumatic system. Check for leaks. Pump aging.
		Slowly decreasing	Sample filter getting clogged with dust. Replace sample filter.
AREF	Constant within ±100 Mm-1 of check-out value	Significantly increasing	Developing AREF valve failure. Replace valve.
			Developing leak in pneumatic system. Check for leaks.
			Debris on mirrors. Contact Technical Support.
Gas Conc (concentration)	Constant for known gas concentration	Decreasing over time	Developing leak in pneumatic system. Check for leaks.

5.3. OPERATIONAL HEALTH CHECKS

Navigate to the Utilities>USB Utilities>Report menu (Figure 5-1) to download a report on the basic operations of the instrument. To download the report for your own viewing on a computer or to send to others, insert a flash drive into a front panel USB port and press the Download button, which is enabled when the instrument detects the flash drive.

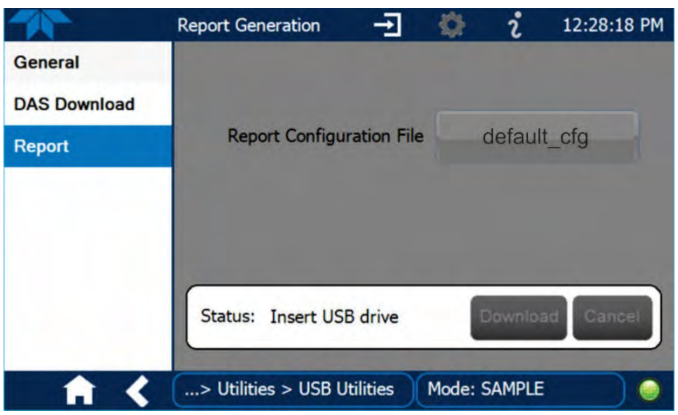


Figure 5-1: Report Generation Page

The report can also be set to generate periodically and sent to a Web services "cloud" where it is available for viewing by Teledyne API technical support personnel. Set this function with two Vars:

Setup>Vars>Upload Report to Cloud: set to True.

Setup>Vars>Report Upload>Interval: edit the number of hours between report uploads.

5.4. SOFTWARE/FIRMWARE UPDATES

There are two ways to check for and acquire updates: either remotely or manually.

5.4.1. REMOTE UPDATES

The instrument must be connected to a network that is connected to the Internet. In the Setup>Instrument menu, select the Remote Update menu and press the Check for Updates button. If an update is available, it can be downloaded through this page.

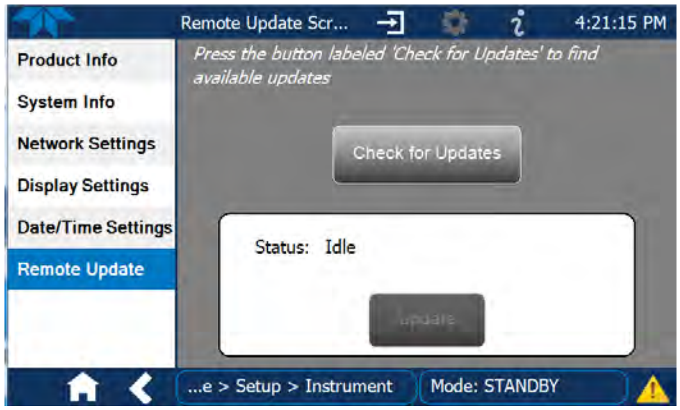


Figure 5-2. Remote Update Page

5.4.2. MANUAL RELOAD/UPDATE PROCEDURES

To reload or update firmware, first contact Technical Support to obtain the applicable file(s): api-techsupport@teledyne.com /+1 800-324-5190.

1. Follow Technical Support's instructions for copying the firmware files to a flash drive.
2. Go to the Utilities>USB Utilities>General menu.

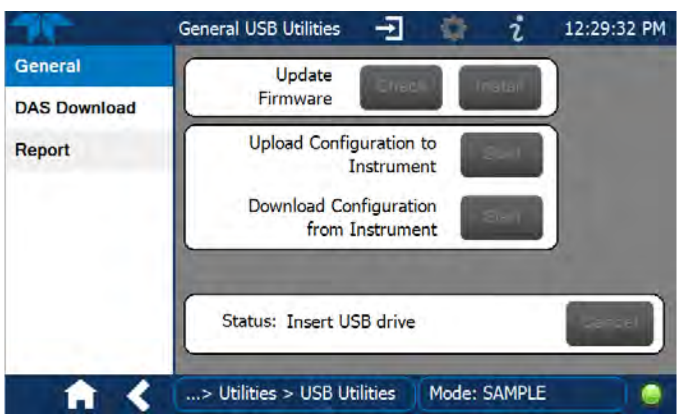


Figure 5-3. Manual Update Page (and other utilities)

3. Insert a flash drive into a front panel USB port and wait for the Status field to Indicates that the drive has been detected.

4. In the Update Firmware field, press the Check button for the instrument to determine whether the firmware on the flash drive is more recent than what is currently installed. Once it's been determined that the firmware is new, the Install button will be enabled; if the firmware version on the flash drive is the same as or older than the current firmware of the instrument, the Install button will not be enabled.
5. Press the Install button and note the messages in the Status field at the bottom of the page. Use the Cancel button if necessary.
6. When complete, as indicated in the Status field, press the Done button, which replaces the Cancel button, and remove the flash drive.
7. Power off and restart the instrument to complete the new firmware installation.

5.5. TIME ZONE CHANGES

There is an option to change between 12-hour and 24-hour format in the Setup>Vars menu (System Time Format). Effectively changing the Time Zone requires a specific procedure as follows:

1. In Setup>Instrument>Date/Time Settings select the applicable Time Zone.
2. Allow adequate time for the selected Time Zone to be properly accepted.
3. Verify: return to Home page then back to the Date/Time Settings page and check that the selected Time Zone is now highlighted.
4. Without making any other changes, power OFF the instrument and power ON again.
5. Once restarted, return to the Date/Time Settings page where the newly selected Time Zone should be highlighted. (If not, it means that not enough time had passed for the instrument to accept the change before the power was cycled OFF).
6. After the Time Zone is implemented first (Steps 1 through 5), then other changes to the date and/or time can be made, and recycling the power is not necessary.

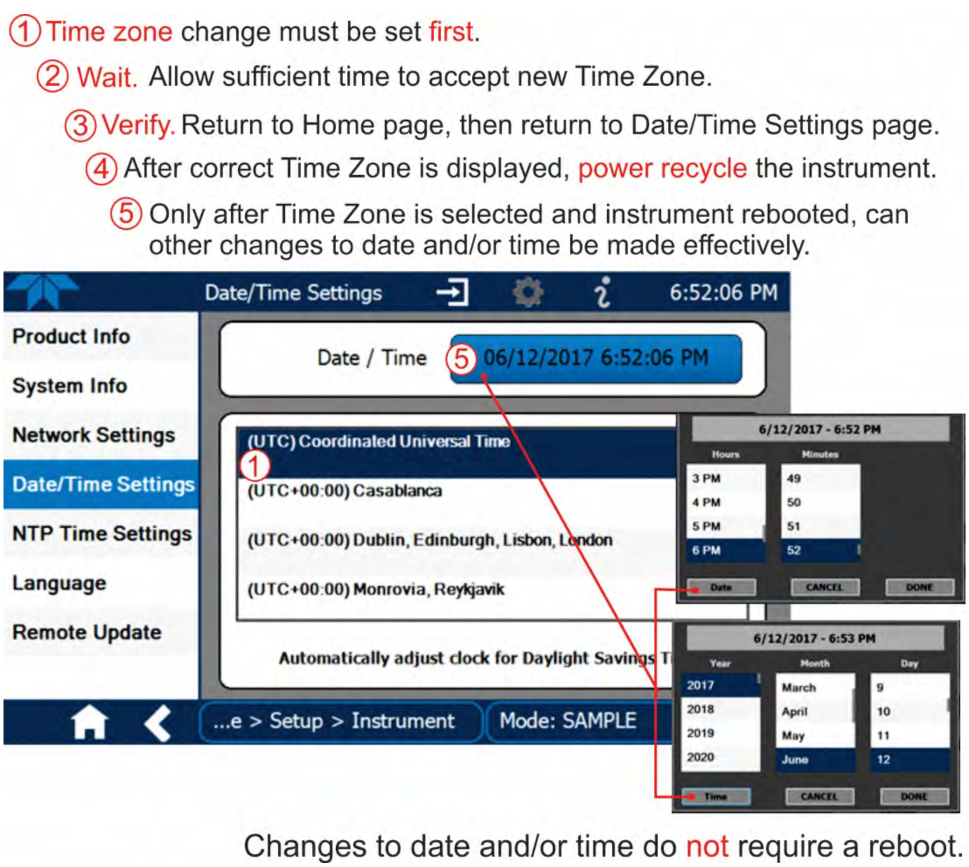


Figure 5-4. Time Zone Change Requirements

5.6. HARDWARE MAINTENANCE PROCEDURES

Perform the following procedures as standard maintenance per Table 5-1.

ATTENTION

COULD DAMAGE INSTRUMENT AND VOID WARRANTY

Ensure there is no power to the unit so that there is no vacuum of any kind when changing anything in the pneumatic flow path. Dust entering the Optical Cell erroneously will contaminate the mirrors.

5.6.1. REPLACING THE SAMPLE FILTER

Inspect the particulate filter often for signs of plugging or contamination.

To change the filter:

1. Turn OFF the analyzer to prevent drawing debris into the instrument.
2. Open the hinged rear panel and disconnect the pneumatic fittings, using the appropriate wrenches, and remove the disposable sample filter.
3. Insert new filter and reconnect pneumatic fittings.
4. Close the front panel

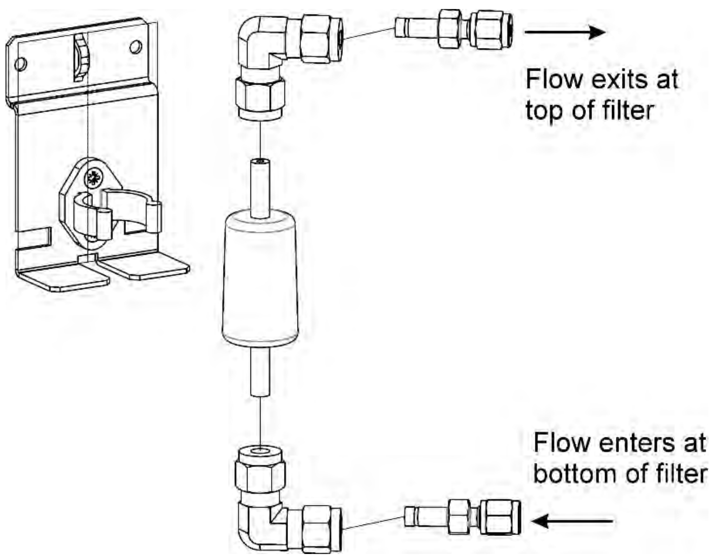


Figure 5-5. Replacing the Sample Filter

5.6.2. REPLACING THE AREF SCRUBBER AND FILTER ASSEMBLY

The AREF filter assembly consists of the AREF DFU filter, which is a backup particulate filter, and the charcoal filter, which is an NO_x gas scrubber.

1. Turn OFF the analyzer (this is important to avoid potential for contamination of the measurement cell), unplug the power cord and remove the cover.
2. Using snips, remove the zip tie holding the pair of fittings to the mounting bracket.

3. Using a wrench, disconnect the fitting that is connected to the AREF filter. Then disconnect the fitting that is connected to the charcoal filter. This will free up the AREF filter assembly.
4. Remove the AREF filter assembly from the mounting brackets.
5. Remove the fittings that connect the two filters to one another.
6. Install replacement filters and reconnect AREF assembly and fittings in reverse order.

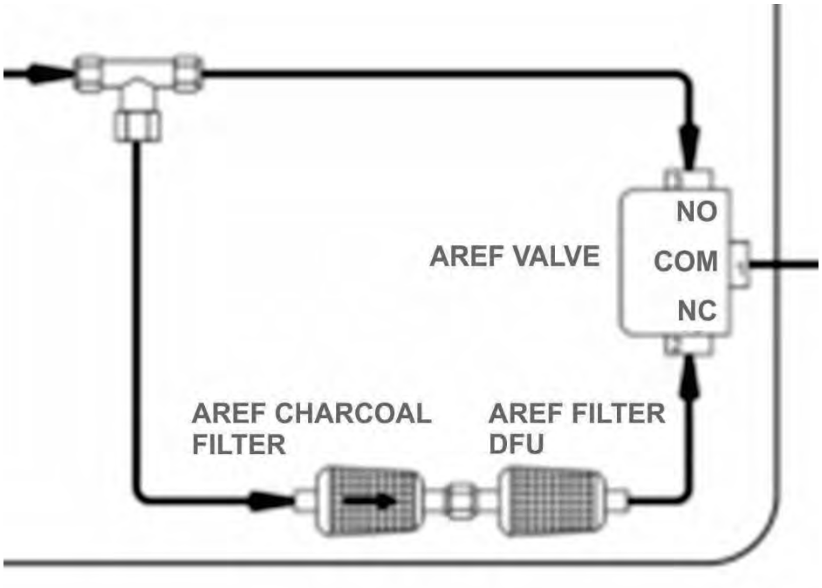


Figure 5-6. Pneumatic Layout of AREF Filter and Charcoal Filter

5.6.3. REPLACING THE INTERNAL PUMP

To replace the internal pump:

1. Turn OFF the analyzer (this is important to avoid potential for contamination of the measurement cell).
2. Remove the top cover of the analyzer.
3. Locate the vacuum pump and using snips, remove the zip ties that secure the four hoses that connect to the pump (two on each side)

   (It may be a good idea to mark the tubes with color codes to be sure they are reconnected properly).
4. Remove the four tubes from the hose barb connections on the pump.
5. Remove the four screws that hold the pump/bracket assembly to the bottom of the chassis.
6. Disconnect the power connector labeled “pump” located about 4 inches down the black/red cable coming from the top of the pump.
7. Pull pump assembly out and set aside.
8. Install replacement pump/bracket assembly.
9. Be sure to reconnect tubes in the proper orientation and zip tie to secure.

10. Replace screws for the pump mounting bracket into the bottom of the chassis, using caution against pinching wires or pneumatic tubes under bracket.
11. Connect the power connector.
12. Once complete, replace the instrument cover and perform a system leak check procedure.

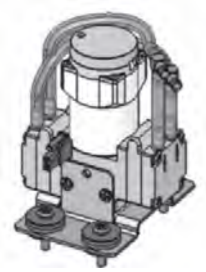


Figure 5-7. Internal Pump

5.6.4. CHANGING THE IZS PERMEATION TUBE OPTION

1. Turn off the analyzer, unplug the power cord and remove the cover.
2. Locate the oven with the internal zero span (IZS) gas permeation tube.
3. Remove the top layer of insulation if necessary.
4. Unscrew the black aluminum cover of the oven (3 screws) using a medium Phillips-head screwdriver.
   - Leave the fittings and tubing connected to the cover.
   - ***Never apply power to the analyzer when the internal pneumatics are disconnected.***
5. Remove the old permeation tube and replace it with the new tube (or store the permeation tube in its original container if the instrument will not be operated for several or more hours).
   - Ensure that the tube is placed into the larger of two holes and that the open permeation end of the tube (plastic) is facing up.
6. Re-attach the cover with three screws and return the insulation if removed.
   - Ensure that the three screws are tightened evenly.
7. Replace the analyzer cover, plug the power cord back in and turn on the analyzer.
8. Carry out a span check to see if the new permeation tube works properly (see Section 4).
9. The permeation rate may need several days to stabilize.

ATTENTION

COULD DAMAGE INSTRUMENT AND VOID WARRANTY

Do not leave instrument turned off for more than 8 hours without removing the permeation tube. Do not ship the instrument without removing the permeation tube. The tube continues to emit NO_2, even at room temperature and will contaminate the entire instrument.

5.6.5. CHECKING FOR PNEUMATIC LEAKS

This section covers a simple leak check and a detailed leak check.

CAUTION - TECHNICAL INFORMATION

Do not exceed 15 psi when pressurizing the system during either Simple or Detailed checks.

5.6.5.1. DETAILED PRESSURE LEAK CHECK

Obtain a leak checker that contains a small pump, shut-off valve, and pressure gauge. Alternatively, a tank of pressurized gas, with the two-stage regulator adjusted to ≤ 10 psi, a shutoff valve and a pressure gauge may be used.

ATTENTION

COULD DAMAGE INSTRUMENT AND VOID WARRANTY

Once tube fittings have been wetted with soap solution under a pressurized system, do not apply vacuum as this will cause soap solution to be sucked into the instrument, contaminating inside surfaces.

1. Turn OFF power to the instrument and remove the instrument cover.
2. Install a leak checker on the **sample inlet** at the rear panel.
3. Cap rear panel ports and cap the pump port.
   - If zero/span valves are installed, disconnect the tubing from the zero and span gas ports and cap the ports (Figure 2-2).
4. Pressurize the instrument with the leak checker, allowing enough time to fully pressurize the instrument.
   - When performing a pressure leak test, always pressurize through the **Sample port (not Exhaust)**.
   - Do not exceed 10 psi pressure.
   - Relieve pressure by removing cap fitting at **Exhaust port**.
5. Once the leak has been located and repaired, the leak-down rate of the indicated pressure should be less than 1 psi in 5 minutes after the pressure is turned off. Replace the instrument cover and restart the analyzer.
6. If the leak still cannot be found, check each tube connection (fittings, hose clamps) with soap bubble solution, looking for fine bubbles.
   - Pressurize the instrument with the leak checker first, allowing enough time to fully pressurize the instrument.
   - Do not exceed 10 psi pressure.
   - Wet the bench with soap solution last.
7. Clean surfaces from soap solution, reconnect the sample and pump lines and replace the instrument cover.
8. Restart the analyzer.

5.6.5.2. Performing a Sample Flow Check

Important

IMPACT ON READINGS OR DATA

Use an external calibrated flow meter capable of measuring flows between 0 and 1000 cm³/min to measure the gas flow rate though the analyzer.

Sample flow checks are useful for monitoring the actual flow of the instrument. A decreasing sample flow may point to slowly clogging pneumatic paths, most likely the sample flow restrictor or the sample filter. To perform a sample flow check:

1. Disconnect the sample inlet tubing from the rear panel SAMPLE port.
2. Attach the outlet port of a flow meter to the sample inlet port on the rear panel.
   - Ensure that the inlet to the flow meter is at atmospheric pressure.
3. Check that the sample flow measured with the external flow meter is within specification.
4. If sample flow is out of specification, first check for kinks in the tubing, then check for leaks.
5. Once kinks and leaks are ruled out, first replace the sample flow restrictor, and if the sample flow is still out of specification, replace the sample filter.
6. If flow is still out of spec, call Technical Support.

5.7. SERVICE AND TROUBLESHOOTING

This section contains methods to identify the source of performance problems with the analyzer and procedures to service the instrument.

CAUTION

The operations outlined in this section must be performed by qualified maintenance personnel only.

WARNING – RISK OF ELECTRICAL SHOCK

Some operations need to be carried out with the analyzer open and running.

Exercise caution to avoid electrical shocks and electrostatic or mechanical damage to the analyzer.

Do not drop tools into the analyzer or leave them after your procedures.

Do not short or touch electric connections with metallic tools while operating inside the analyzer.

Use common sense when operating inside a running analyzer.

The analyzer has been designed so that problems can be rapidly detected, evaluated and repaired. During operation, it continuously performs diagnostic tests and provides the ability to evaluate its key operating parameters without disturbing monitoring operations.

A systematic approach to troubleshooting will generally consist of the following five steps:

1. Note any Alerts and take corrective action as necessary (see Table 5-3).
2. Examine the values of all basic functions in the Dashboard and compare them to factory values. Note any major deviations from the factory values and take corrective action.
3. Use the internal electronic status LEDs to determine whether the electronic communication channels are operating properly. Refer to Figure 5-8, Figure 5-9, and Figure 5-10
4. Suspect a leak first!
    - Customer service data Indicates that the majority of all problems are eventually traced to leaks in the internal pneumatics of the analyzer or the diluent gas and source gases delivery systems.
    - Check for gas flow problems such as clogged or blocked internal/external gas lines, damaged seals, punctured gas lines, damaged / malfunctioning pumps, etc.
5. Follow the procedures defined in Section 2.3.4.3 to confirm that the analyzer's vital functions are working.

5.7.1. FAULT DIAGNOSIS WITH ALERTS

Table 5-3 lists brief descriptions of warning Alerts that may occur during start up and describes their possible causes for diagnosis and troubleshooting.

It should be noted that if more than two or three warning Alerts occur at the same time, it is often an indication that some fundamental sub-system (power supply, smart module, mainboard) has failed rather than an indication of the specific failures referenced by the warnings.

Table 5-3. Warning Alerts, Fault Conditions and Possible Causes

WARNING	FAULT CONDITION	POSSIBLE CAUSES
AUTO REF WARNING	AREF value outside allowable limit.	Drift in baseline loss due to large leak. Sample filter bypassed. Mirrors may be dirty – contact Technical Support to confirm
CANNOT DYN SPAN [1]	Dynamic Span operation failed. (Contact closure span calibration failed while *DYN_SPAN* was set to *ON*).	Measured concentration value is too high or low Concentration Slope value to high or too low
CANNOT DYN ZERO [2]	Dynamic Zero operation failed. (Contact closure zero calibration failed while *DYN_ZERO* was set to *ON*).	Measured concentration value is too high Concentration Offset value to high

WARNING	FAULT CONDITION	POSSIBLE CAUSES
CELL PRESS WARN	Cell pressure is too high or too low for accurate NO, NO_2, NO_x readings. (<5 in-Hg or > 35 in-Hg). Normally 29.92 in-Hg at sea level decreasing at 1 in-Hg per 1000 ft of altitude (with no flow – pump disconnected).	If Cell Pressure is < 5 in-Hg: •Failed Pressure Sensor/circuitry If Cell Pressure is > 35 in-Hg: •Bad Pressure Sensor/circuitry •Pressure too high at Sample Inlet.
CONFIG INITIALIZED	Configuration and Calibration data reset to original Factory state or erased.	Failed Disk on Module User erased data
DATA INITIALIZED	Data Storage in DAS was erased before the last power up occurred.	Failed Disk-on-Module User cleared data.
SAMPLE PRESS WARN	Sample pressure is too high or too low for accurate NO, NO_2, NO_x readings. (<15 in-Hg or > 35 in-Hg). Normally 29.92 in-Hg at sea level decreasing at 1 in-Hg per 1000 ft of altitude (with no flow – pump disconnected).	If Sample Pressure is < 15 in-Hg: •Blocked Particulate Filter •Blocked Sample Inlet/Gas Line •Failed Pressure Sensor/circuitry If Sample Pressure is > 35 in-Hg: •Bad Pressure Sensor/circuitry •Pressure too high at Sample Inlet.
SYSTEM RESET	The computer has rebooted.	This message occurs at power on. If it is confirmed that power has not been interrupted: Failed +5 VDC power Fatal Error caused software to restart Loose connector/wiring

[1] Clears the next time successful zero calibration is performed.
[2] Clears the next time successful span calibration is performed.

5.7.2. FAULT DIAGNOSIS WITH DASHBOARD FUNCTIONS

In addition to being useful as predictive diagnostic tools, the functions viewable in the Dashboard can be used to isolate and identify many operational problems.

The acceptable ranges for these functions are listed in the "Nominal Range" column of the analyzer's *Final Test and Validation Data Sheet* shipped with the instrument. Values outside these acceptable ranges Indicates a failure of one or more of the analyzer's subsystems. Functions whose values are still within acceptable ranges but have significantly changed from the measurement recorded on the factory data sheet may also Indicates a failure.

Make note of these values for reference in troubleshooting.

5.7.3. USING THE DIAGNOSTIC SIGNAL I/O FUNCTIONS

The signal I/O functions in the Utilities>Diagnostics menu allows access to the digital and analog functions in the analyzer. Some of the digital signals can be controlled through the Setup menu. These signals are useful for troubleshooting in three ways:

- The technician can view the raw, unprocessed signal level of the analyzer's critical inputs and outputs.

- Many of the components and functions that are normally under algorithmic control of the CPU can be manually exercised.
- The technician can directly control the signal level Analog and Digital Output signals.

This allows the technician to observe systematically the effect of directly controlling these signals on the operation of the analyzer. Use the Utilities>Diagnostics menu to view the raw voltage of an input signal or the Setup menu to control the state of an output voltage or control signal.

5.7.4. FAULT DIAGNOSIS WITH LEDS

The following illustrations show connectors and LEDs that can indicate where issues may lie. Figure 5-8 shows the layout for the mainboard; Figure 5-9 shows the layout for the CAPS DAQ smart board, and Figure 5-10 shows the layout for the ozone tower smart module.

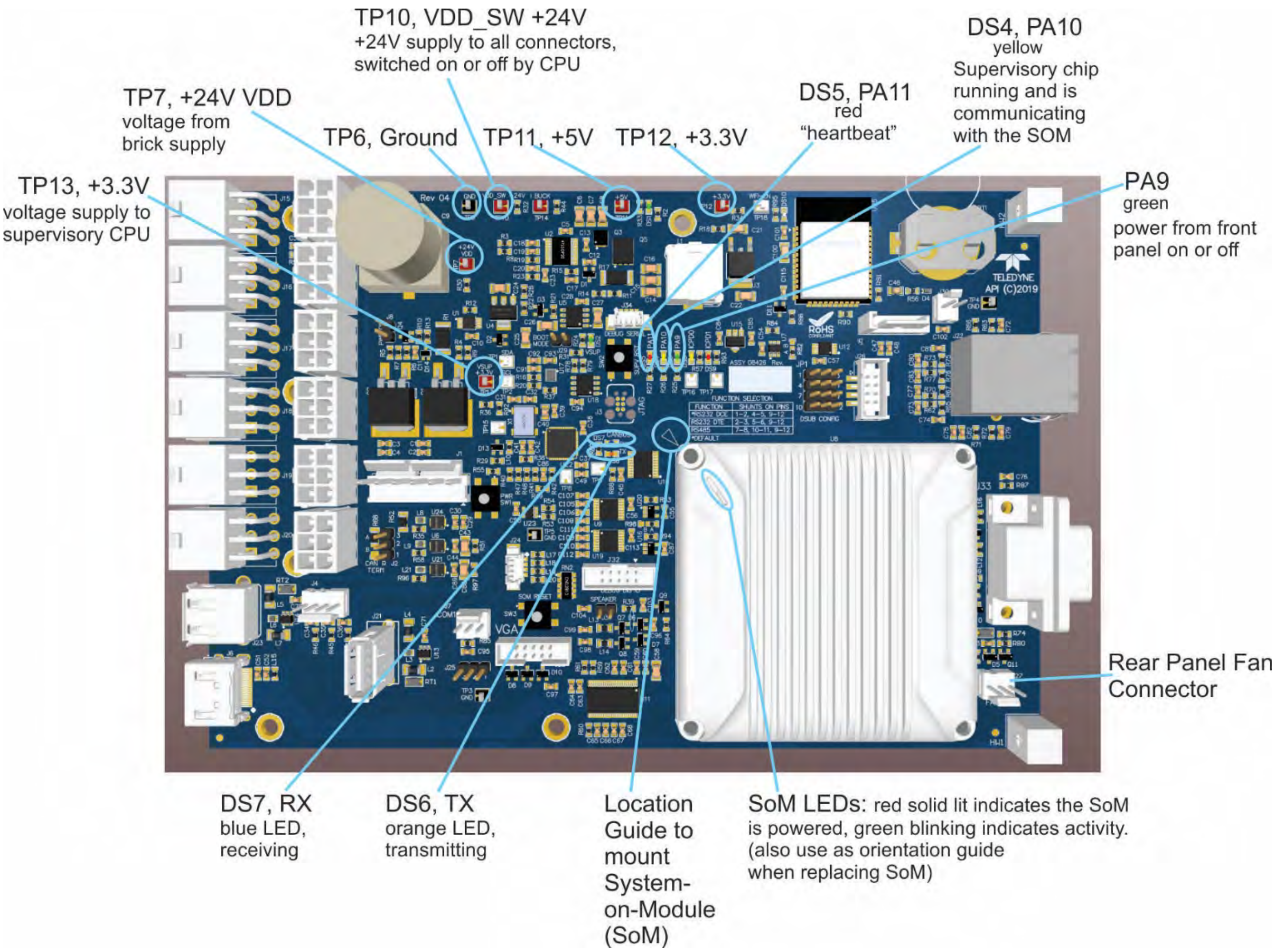


Figure 5-8. N500 Mainboard

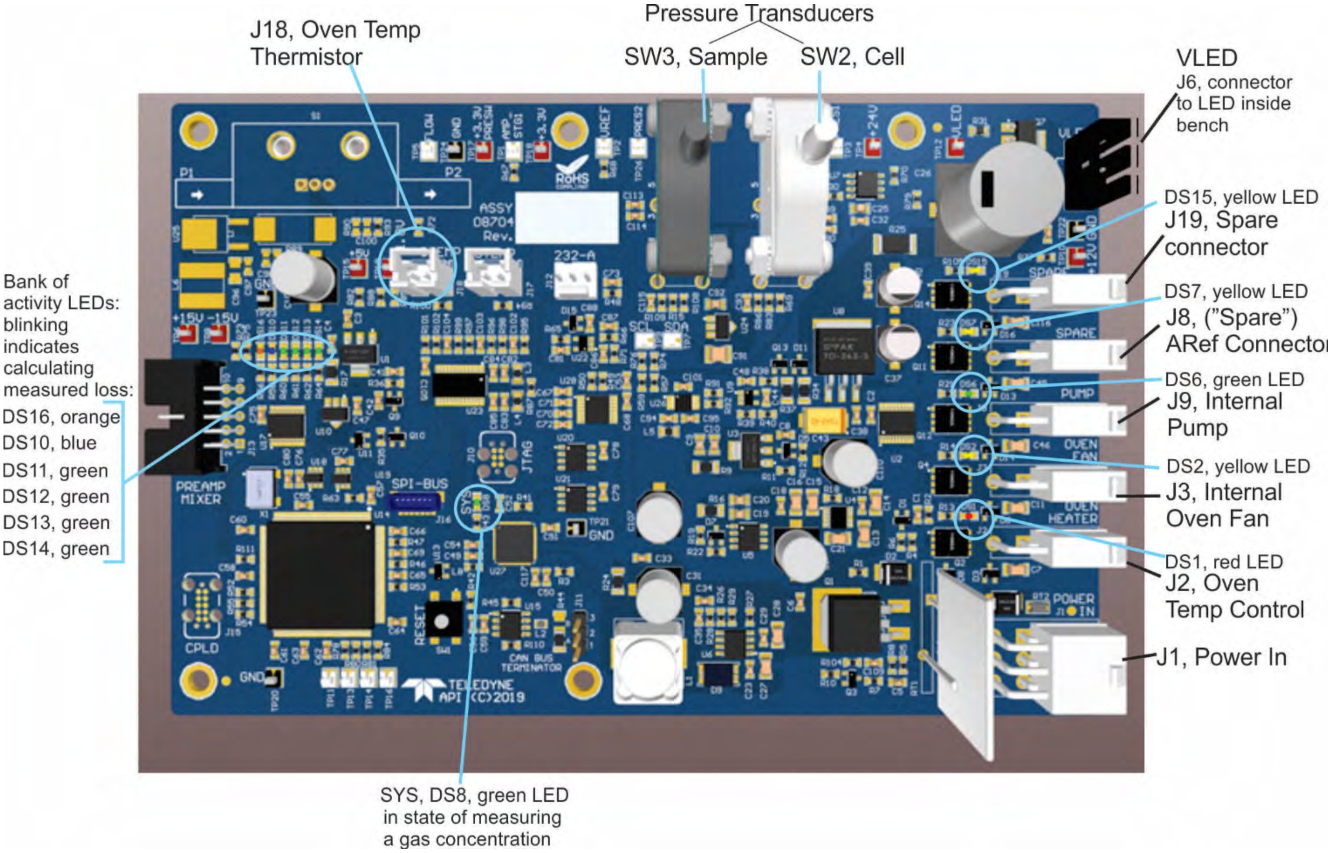
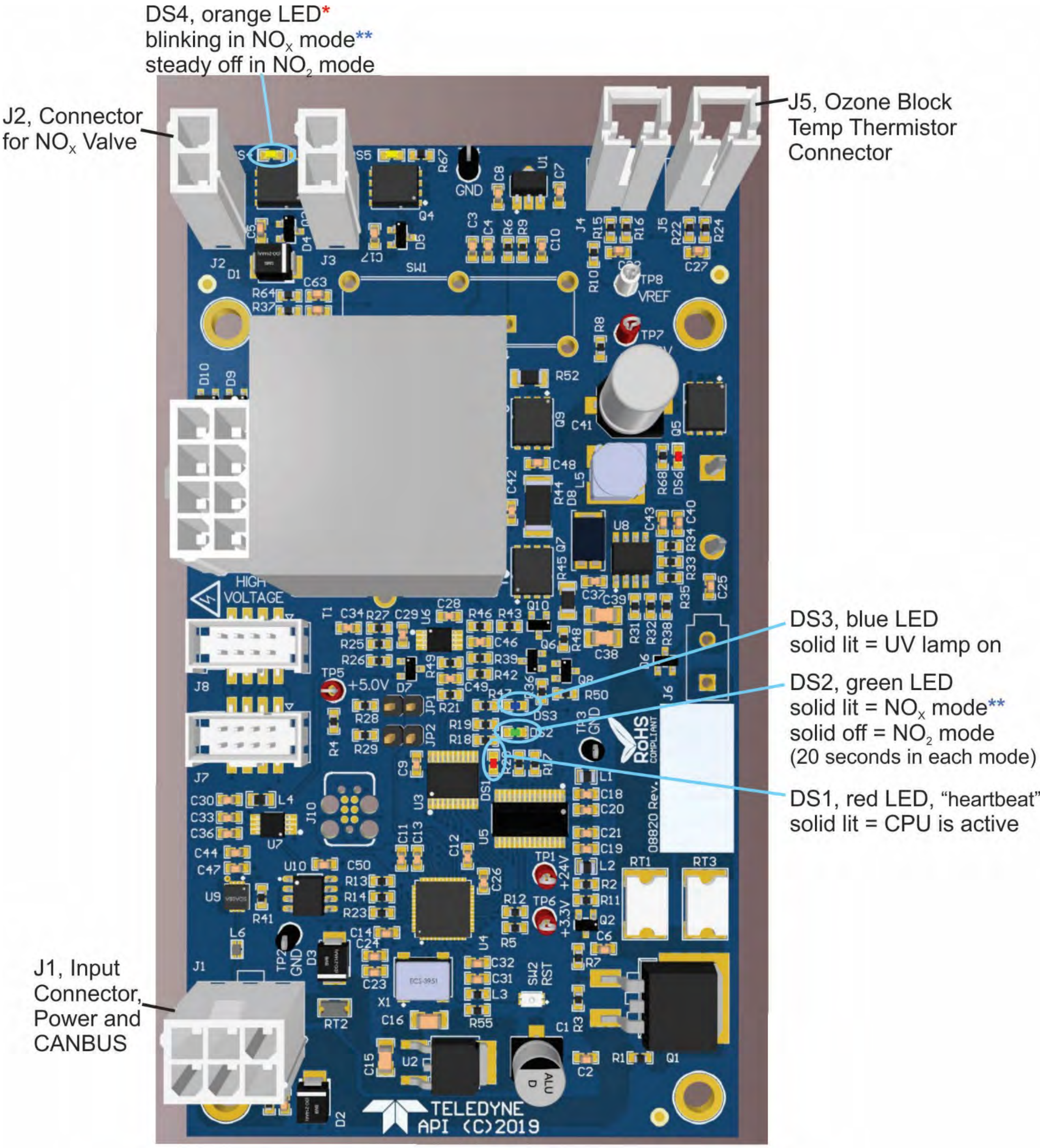


Figure 5-9. N500 CAPS DAQ Smart Board



*DS4 stays off until the end of a 20-minute warm-up period after initial power-on, unless it is forced on through the O3 Gen Override menu.

**DS2 and DS4: an audible clicking sound must also be present to indicate that NO_X mode is functioning.

Figure 5-10. N500 Ozone Tower Smart Board

5.7.5. CALIBRATION PROBLEMS

This section describes possible causes of calibration problems.

5.7.5.1. Negative Concentrations

Negative concentration values can be caused by calibration error: If the zero air were contaminated, and the analyzer was calibrated at "zero", the analyzer may report a negative value when measuring air that contains little or no NO_x.

5.7.5.2. Absence of Analyzer Response to Sample Gas

If the instrument shows no response (display value is near zero), even though sample gas is supplied properly, and the instrument seems to perform correctly:

1. Confirm the lack of response by supplying NO2 span gas of about 80% of the range value to the analyzer.
2. Check the sample pressure and cell pressure for proper value.
3. Check for disconnected cables to the sensor module.
4. If delivering NO gas, check that the Lamp Current is 7-10 mA and the NOx valve is Pulsing in NOx mode. There is an audible clicking sound when the valve activates.

5.7.5.3. Unstable Zero and Span

Leaks in the instrument or in the external gas supply and vacuum systems are the most common source of unstable and non-repeatable concentration readings.

1. Check for leaks in the pneumatic systems as described in Section 5.6.5.
2. Consider pneumatic components in the gas delivery system outside the analyzer such as a change in zero air source (ambient air leaking into zero air line) or a change in the span gas concentration due to zero air or ambient air leaking into the span gas line.
3. Once the instrument passes a leak check, do a flow check (this chapter) to ensure that the instrument is supplied with adequate sample and ozone air.
4. Confirm the sample pressure, cell pressure, and sample flow are correct and steady.
5. Verify that the sample filter element is clean and does not need to be replaced.

5.7.5.4. Inability to Span - Deactivated SPAN Button

In general, the analyzer will deactivate certain buttons whenever the actual value of a parameter is outside of the expected range for that parameter. If the Span is grayed out, the actual concentration must be outside of the range of the expected span gas concentration, which can have several causes.

1. Verify that the expected concentration is set properly to the actual span gas concentration in the CONC sub-menu.
2. Confirm that the NO_2 span gas source is accurate.
   - This can be done by comparing the source with another calibrated analyzer.

3. Check for leaks in the pneumatic systems as described in Section 5.6.5.
   - Leaks can dilute the span gas and, hence, the concentration that the analyzer measures may fall short of the expected concentration defined in the CONC sub-menu.

5.7.5.5. Inability to Zero - Deactivated ZERO Button

In general, the analyzer will deactivate certain buttons whenever the actual value of a parameter is outside of the expected range for that parameter. If the Zero button is grayed out, the actual gas concentration must be significantly different from the actual zero point (as per last calibration), which may be for any of several reasons.

1. Confirm that there is a good source of zero air.
2. Check to ensure that there is no ambient air leaking into zero air line.
3. Check for leaks in the pneumatic systems as described in Section 5.6.5.

5.7.5.6. Non-Linear Response

The analyzer was factory calibrated to a high level of NO_2 and should be linear to within 1% of full scale. Common causes for non-linearity are:

- Leaks in the pneumatic system:
  - Leaks can add ambient air, zero air or span gas to the current sample gas stream, which may be changing in concentrations as the linearity test is performed.
  - Check for leaks as described in Section 5.6.5.
- The calibration device is in error:
  - Check flow rates and concentrations, particularly when using low concentrations.
  - If a mass flow calibrator is used and the flow is less than 10% of the full scale flow on either flow controller, you may need to purchase lower concentration standards.
- The standard gases may be mislabeled as to type or concentration.
  - Labeled concentrations may be outside the certified tolerance.
- The sample delivery system may be contaminated.
  - Check for dirt in the sample lines or reaction cell.
- Dilution air contains sample or span gas.
- Incoming concentrations may not be linear.
  - Check input bottles.
- Span gas overflow is not properly vented and creates a back-pressure on the sample inlet port. Also, if the span gas is not vented at all and does not supply enough sample gas, the analyzer may be evacuating the sample line.
  - Ensure to create and properly vent excess span gas.

5.7.6. OTHER PERFORMANCE PROBLEMS

Dynamic problems (i.e., problems that only manifest themselves when the analyzer is monitoring sample gas) can be the most difficult and time consuming to isolate and resolve. The following section provides an itemized list of the most common dynamic problems with recommended troubleshooting checks and corrective actions.

5.7.6.1. Excessive Noise

Excessive noise levels under normal operation usually Indicates leaks in the sample supply or the analyzer itself.

- Ensure that the sample or span gas supply is leak-free, and carry out a detailed leak check as described earlier in this chapter.

Other sources of measurement noise may be related to cabling issues or large ambient Temperature changes.

- Gain access to the instrument, when powered down, and reset the cable connectors.
- Do not locate the analyzer in the vicinity of the air conditioning ducting.

5.7.6.2. Slow Response

If the analyzer starts responding too slow to any changes in sample, zero or span gas, check for the following:

- Dirty or plugged sample filter or sample lines.
- Sample inlet line is too long.
- Dirty or plugged flow restrictor. Check flows, pressures and, if necessary, change restrictor.
- Wrong materials in contact with sample - use glass, stainless steel or Teflon materials only.
- Insufficient time for purging lines upstream of the analyzer. Wait for stability is reached.
- Insufficient time for calibration gas source to stabilize. Wait until stability is reached.

5.7.6.3. AREF Warnings

Auto Reference (AREF) warnings occur if the signal measured during an AREF cycle is higher than 1100 Mm-1.

Note	**The AREF warning displays the value of the Auto Reference reading when the warning occurs.** **(Also note that there will not be an AREF warning if the AREF feature was disabled due to prolonged time in CAL mode. Ensure the instrument is returned to SAMPLE mode as soon as a calibration has been completed).**

- If this value is higher than 1100 Mm-1, check that the Auto Reference valve is operating properly.
  - To do so, use the Utilities>Diagnostics>Digital Outputs menu to toggle the valve on and off.
  - Listen to hear whether the valve is switching, and see if its D7 LED (associated with J8 connector) on the CAPS DAQ board lights accordingly
  - Check the power supply to the valve (24 V to the valve should turn on and off when measured with a voltmeter).

Note **It takes only a small leak across the ports of the valve to show excessive Auto Zero values when supplying high concentrations of span gas.**

If the Auto Reference valve is working properly, then the problem could be due to dirty mirrors. Please contact Technical Support (Section 5.9) to confirm this and to rule out other possibilities.

5.7.7. SUBSYSTEM CHECK FOR TROUBLESHOOTING

The preceding sections of this manual discussed a variety of methods for identifying possible sources of failures or performance problems within the analyzer. This section describes how to determine if a certain component or subsystem is actually the cause of the problem being investigated.

5.7.7.1. AC MAIN POWER

WARNING – ELECTRICAL SHOCK HAZARD

Should the AC power circuit breaker trip, investigate and correct the condition causing this situation before turning the analyzer back on.

The instrument’s electronic systems will operate with any of the specified power within the 100 VAC to 240 VAC, at 47 Hz to 63 Hz. Using the properly rated power cord, the instrument will power on when the rear panel Hard Power switch is placed in the ON position. (If the power source is disrupted, the instrument will turn on once the power is restored. If the instrument doesn’t start, check the following possible causes and possible solutions:

- Check the power cord for damage, such as whether it’s cut or burned.
- Check that the power cord is adequately rated for the instrument’s specified power rating.
- Check that the power source is of the proper voltage for the instrument’s specified power rating.
- If there are no findings in the preceding steps, then note whether the instrument had been opened for maintenance; if so, place the rear panel Hard Power switch in the OFF position, and disconnect the power cord; then reopen the instrument and check that no wiring had been dislodged, and no tools were left inside.
- If no other reason can be found for the instrument not powering on, then check the fuse with an ohmmeter to determine its viability: carefully follow the instructions in Section 5.7.8.1 to remove the fuse for testing.
    - If the fuse is blown, replace it with a fuse of the correct specifications as instructed in Section 5.7.8.1.
- If the fuse is not blown, or if the replacement fuse blows, then call Technical Support (Section 5.9).

5.7.7.2. LCD/DISPLAY MODULE

Assuming that there are no wiring problems and that the DC power supply is operating properly, the display screen should light and show the splash screen and other indications of its state as the CPU goes through its initialization process.

5.7.7.3. O_3 GENERATOR MODULE

The ozone generator can fail in three ways, electronically (printed circuit board) and functionally - UV Lamp issues or NOx valve issues. Assuming that air is supplied properly to the generator, the generator should automatically turn on 30 minutes after the instrument is powered up. However, if the generator appears to be working properly but the sensitivity or calibration of the instrument is reduced, suspect a leak in the ozone generator pneumatics or a NOx valve that isn't cycling On/Off in NOx mode.

A leak in the dryer or between the dryer and the generator can reduce sensitivity and cause performance drift. Carry out a leak check (Section 5.6.5).

5.7.7.4. O_3 GENERATOR OVERRIDE

This feature in the Utilities>Diagnostics menu is used to manually turn the ozone generator off and on. This should be done before disconnecting the generator, to prevent ozone from leaking out, and after a system restart if the user does not want to wait the 30-minute warm-up time.

5.7.7.5. INTERNAL SPAN GAS GENERATOR AND VALVE OPTIONS

The zero/span valves and internal span gas generator options need to be enabled in the software (contact the factory on how to do this).

The semi-permeable PTFE membrane of the permeation tube is severely affected by humidity. Variations in humidity between day and night are usually enough to yield highly variable output results. If the instrument is installed in an air-conditioned shelter, the air is usually dry enough to produce good results. If the instrument is installed in an environment with variable or high humidity, variations in the permeation tube output will be significant. In this case, a dryer for the supply air is recommended (dewpoint should be –20° C or less).

The permeation tube of the internal span gas generator option is heated with a proportional heater circuit, and the temperature is maintained at 50°C ±1°C. Check the IZS Temp in the Dashboard or the IZS Temp Raw signal in the Utilities>Diagnostics>Analog Outputs menu (configurable in the Setup>Analog Outputs menu). At 50° C, the temperature signal from the IZS thermistor should be around 2500 mV.

5.7.7.6. RS-232 COMMUNICATIONS

Teledyne API's analyzers use the RS-232 communications protocol to allow the instrument to be connected to a variety of computer-based equipment. Problems with RS-232 connections usually center around such things as incorrect connector configuration, incorrect software settings, improper/incomplete seating of the internal cable. Do not do anything inside the instrument without first contacting Technical Support (Section 5.9). For additional information, see Section 2.3.1.4 under "Serial Connection."

5.7.8. SERVICE PROCEDURES

This section contains some procedures that may need to be performed when a major component of the analyzer requires repair or replacement.

Note	**Regular maintenance procedures are discussed in Section 5.5 and are not listed here). Also, there may be more detailed service notes for some of the below procedures. Contact Teledyne API's Technical Support Department.**

WARNING – ELECTRICAL SHOCK HAZARD

Unless the procedure being performed requires the instrument to be operating, turn it off and disconnect power before opening the analyzer and removing, adjusting or repairing any of its components or subsystems.

CAUTION – QUALIFIED TECHNICIAN

The operations outlined in this chapter are to be performed by qualified maintenance personnel only.

5.7.8.1. FUSE REPLACEMENT PROCEDURE

ATTENTION	**COULD DAMAGE INSTRUMENT AND VOID WARRANTY** **Fuses do not typically fail without definite cause. Do not attempt to replace until after all measures to detect the cause of a power failure, per Section 5.7.7.1, have been carried out, including Soft Power switch LED not lit (neither solid nor blinking), but Hard Power switch is in ON position and instrument's power cord properly connected at both ends. If an ohmmeter shows that the fuse is good, or if a new fuse blows, call Technical Support (Section 5.9).**

WARNING – ELECTRICAL SHOCK HAZARD

Never pull out fuse drawer without ensuring that the Hard Power switch is in OFF position and power cord disconnected, to ensure there is no power to the instrument before checking/changing fuse.

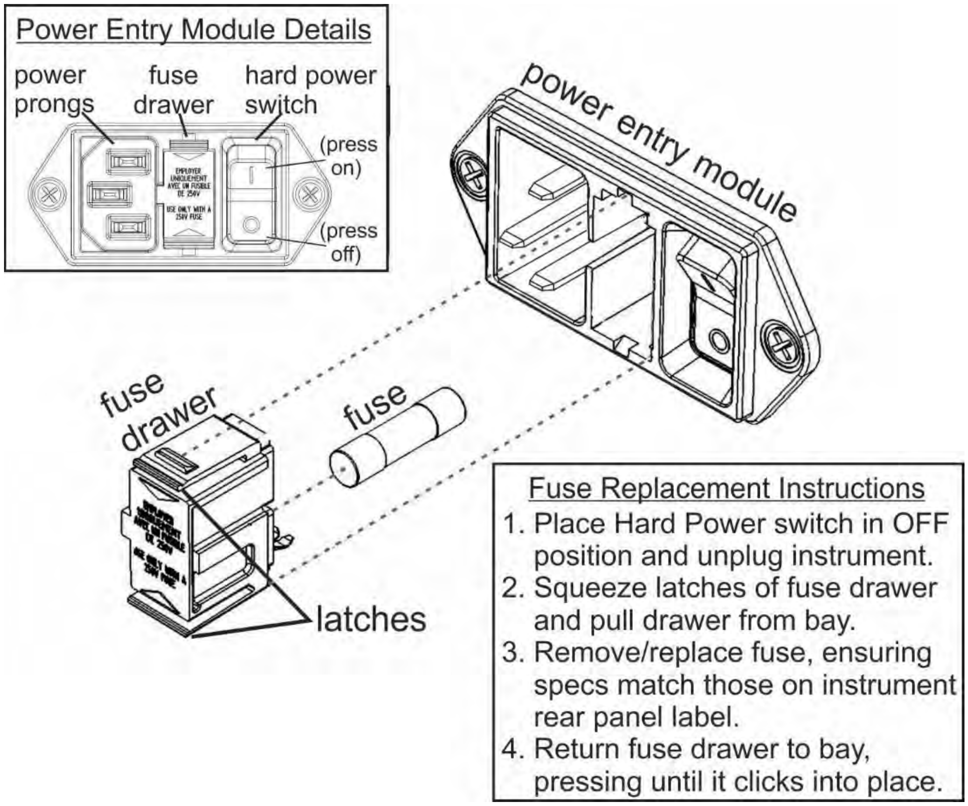


Figure 5-11. Fuse Access

5.7.8.2. O_3 Generator Replacement

The ozone tower has a printed circuit board (see Figure 2-3). The board has a blue LED that, when lit, indicates ozone is being generated. To replace the ozone generator:

1. Turn off the analyzer power; remove the power cord and the analyzer cover.
2. Disconnect the tubing from the ozone generator. ***Never apply power to the analyzer when the internal pneumatics are disconnected.***
3. Unplug the CANBUS cable that is connected to the PCA.
4. Unscrew the two mounting screws that attach the ozone generator to the chassis and take out the entire assembly.
5. With a complete replacement generator with circuit board and mounting bracket attached, simply reverse the above steps to replace the current generator.

Note	**Ensure to carry out a leak check (Section 5.6.5) and a recalibration after the analyzer has warmed up for about 60 minutes.**

5.7.8.3. SAMPLE CONDITIONER ASSEMBLY REPLACEMENT

The sample conditioner assembly includes a permeation dryer, a Charcoal scrubber (AREF), and a DFU filter.

Change the dryer component as follows:

1. Turn off power to the analyzer and pump and remove the power cord and the analyzer cover.
2. Disconnect tubing to and from assembly. ***Never apply power to the analyzer when the internal pneumatics are disconnected***.
3. Noting the orientation, unscrew the mounting screws and remove the assembly.
4. Install the new assembly in the same orientation as noted in the preceding Step, and secure in place with the mounting screws.
5. Reattach tubing to and from assembly.
6. Carry out a detailed leak check (see Section 5.6.5.1).
7. Close the analyzer and reconnect the power cord.
8. Power up pump and analyzer and re-calibrate the instrument after it stabilizes.

5.8. FREQUENTLY ASKED QUESTIONS

The following list was compiled from the Teledyne API's Technical Support Department's ten most commonly asked questions relating to the analyzer.

QUESTION	ANSWER
Why does the Enter button sometimes disappear in some of the menus?	Sometimes the Enter button will disappear if you input a setting that is invalid or out of the allowable range for that parameter, such as trying to set the 24-hour clock to 25:00:00 or a range outside its allowable limits. Once you adjust the setting to an allowable value, the Enter button will re-appear.
Why is the ZERO or SPAN button deactivated during calibration?	This happens when the measured gas concentration differs significantly from the span or zero gas concentration value entered by the user. This prevents accidental recalibration of the analyzer to an out-of-range response curve. EXAMPLE: The span set point is 400 ppb but gas concentration being measured is only 50 ppb.
How do I enter or change the value of my Span Gas?	See Section 4.2.1.2.
Can I automate the calibration of my analyzer?	Any analyzer with zero/span valve or IZS option can be automatically calibrated using the instrument's AutoCal feature (Section 4.3).
Can I use the IZS option to calibrate the analyzer?	Yes. However, the accuracy of the IZS option's permeation tube is only ±5%. To achieve highest accuracy, it is recommended to use cylinders of calibrated span gases in combination with a zero air source.
How do I measure the sample flow?	For accurate measurement, attach a calibrated volumetric flow meter to the sample inlet port, and get a reading while the instrument is operating. The sample flow should be as specified in Table 1-1. (To calibrate, use the Utilities>Diagnostics menu; refer to Section 5.6.5.2).
How often do I need to change the particulate filter?	Refer to the Maintenance Schedule in Table 5-1. Keep in mind that highly polluted sample air may require more frequent changes.
How long does the sample pump last?	The sample pump should last one to two years and the pump head should be replaced when necessary. (Refer to Maintenance Schedule Table 5-1).
Why does my RS-232 serial connection not work?	There are several possible reasons: • The wrong cable: please use the provided or a generic "straight-through" cable (do not use a "null-modem" type cable) and ensure the pin jumpers are correct (Section 2.3.1.4 under Serial Connection). • The baud rate of the analyzer's COM port does not match that of the serial port of your computer/data logger (Table 2-12).
How do I set up and use the contact closures (Control Inputs) on the rear panel of the analyzer?	See Section 2.3.1.3.

5.9. TECHNICAL ASSISTANCE

For spare parts, or if this manual and its troubleshooting & service section do not solve your problems, technical assistance may be obtained from:

Teledyne API Technical Support
9970 Carroll Canyon Road
San Diego, California 92131-1106 USA

Toll-free Phone:	+1 800-324-5190
Phone:	+1 858-657-9800
Fax:	+1 858-657-9816
Email:	api-techsupport@teledyne.com
Website:	http://www.teledyne-api.com/

6. PRINCIPLES OF OPERATION

The Cavity Attenuated Phase Shift (CAPS) NO_X monitor operates as an optical absorption spectrometer that yields both reliable and accurate measurements down to sub ppb concentrations, with lower noise levels than chemiluminescence-based monitors. The CAPS method uses light from a blue Ultraviolet (UV) light emitting diode (LED) centered at 405 nm, a measurement cell with high reflectivity mirrors located at either end to provide an extensive optical path length, and a vacuum photodiode detector. These components are assembled into the optical cell which resides in a temperature-controlled oven. The oven raises the ambient temperature of the sample gas to 45 degrees Celsius. This mitigates the formation of moisture on the surfaces of the mirrors while also minimizing changes in the absorption coefficient due to temperature fluctuations.

Optical absorption is well-defined and is described by Beer's Law, where the Absorbance (lost light) is directly proportional to both the path-length and concentration of the absorbing gas.

$$A = \varepsilon\, l\, c$$

(A = Absorbance, ε = Molar absorptivity, l = Mean path Length, c = concentration)

The CAPS method employed in the N500 is unique in that it applies this fundamental optical absorption law in the frequency domain, rather than using relative changes in light intensity as the primary signal. Ultraviolet light (UV) from the modulating high intensity LED enters a near confocal optical cell (Figure 6-1) through the rear of mirror A. The intensity of the light, as observed by the detector, which is also modulating at a slightly different frequency, located behind Mirror B, builds exponentially in the cell while the LED is ON. The opposite is true when the LED is OFF. Because both mirrors are highly reflective at 405 nm, a prominent absorption band for NO_2, the light takes a considerable amount of time to plateau in the absence of the absorbing gas. However, when NO_2 is present, the mean path length traveled by the light is significantly reduced. This has two effects on the observed intensity as measured by the detector:

- The light plateau intensity level is lower, more importantly for the N500
- The light intensity plateaus sooner.

Thus, an observed phase shift from the modulating LED is detected (Figure 6-2). The phase shift is largest when measuring zero air, decreases when NO_2 is present, and is proportionate to the concentration of the NO_2.

Both the LED and the Detector are modulated ON and OFF such that the observed signal has a much lower frequency, equal to the difference between the modulated frequencies and is referred to as a beat frequency. The system hardware and software take advantage of this, as it makes it easier to post process the signal using a micro controller. The technique is known as heterodyning.

The instrument translates the phase shift from the presence of absorbing gas into a concentration measurement. Typical absorption techniques of other analyzers take a reference and measure value of the light intensity "level" in order to derive concentration and compensate for source drift. Using the CAPS technique, the amount of phase shift remains constant for a given concentration, even if the LED drifts over time. This measurement approach offers many advantages over traditional (or "Chemi") analyzers, such as faster response (single gas stream), lower noise at span, and more importantly, greater specificity.

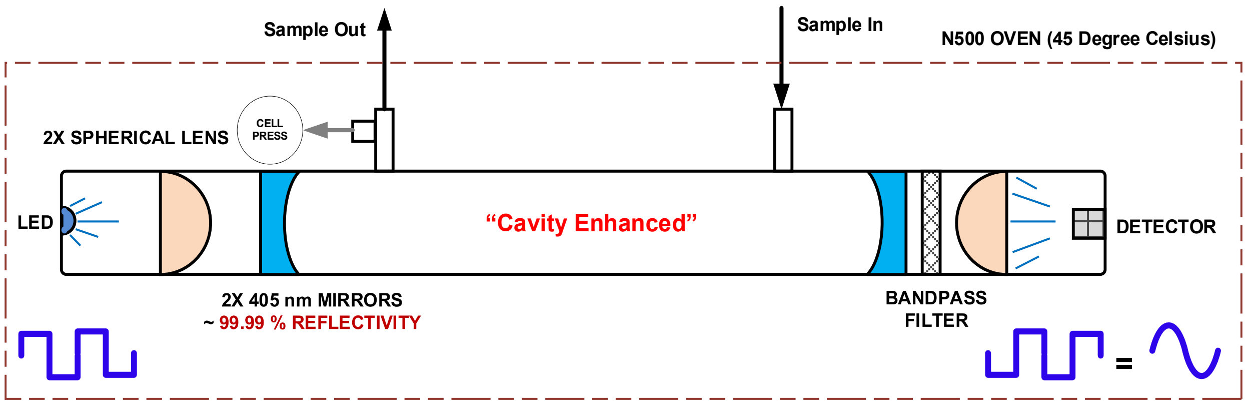


Figure 6-1. N500 Optical Absorption Cell

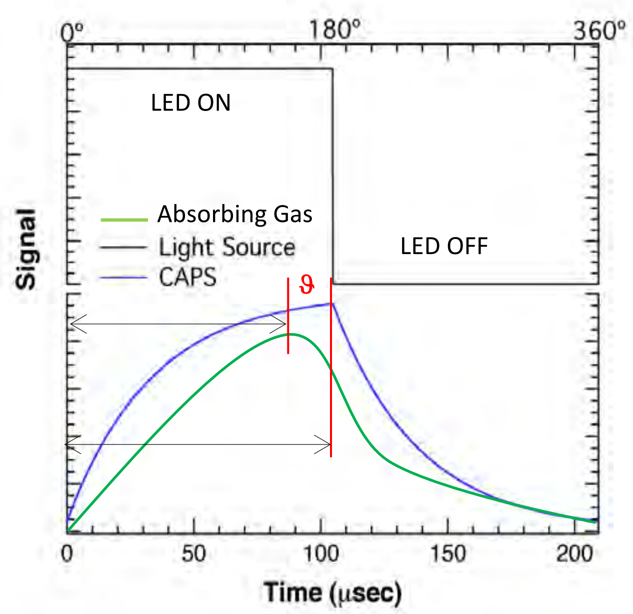


Figure 6-2. Phase Shift Representation of Increased Concentration of NO_2

(Black = LED State, Blue = Light build up in the absence of NO_2, Green = phase shifted\attenuated light).

6.1. PNEUMATIC OPERATION

An internal vacuum pump, which is located pneumatically downstream from all the instrument's other components, pulls the sample gas through the instrument's pneumatic pathway. The flow rate is controlled by a flow restrictor placed upstream of the sensor.

After being pulled through a series of filtering and conditioning components, the sample gas is routed through the sensor for a true NO_2 reading; the sample gas is alternately titrated with higher levels of ozone where the sensor reads a second, higher NO_2 concentration (NOx Mode), after which the two readings are used in calculations to provide a NO_X value and an NO concentration. The analyzer alternates between NO_2 mode for 20 seconds and then NO_X mode for 20 seconds.

The alternating valve toggling for ozone titration is very rapid and follows a pattern of signal processing states that the Dashboard displays in the "SigProc State" parameter as described in Table 6-1. To ensure accuracy, the analyzer periodically goes into AREF mode to run a background measurement while in Sample mode and adjusts for any baseline drift that may occur.

Table 6-1. Sensor Signal Processing States

STATE	DESCRIPTION
IDLE	Transitioning between measurement modes (very brief state, typically not visible)
NO2_WAIT	Flushing the cell of the prior NOx sample before taking the NO_2 measurement.
NO2_SAMPLE	Reading NO_2 concentration.
NOx_WAIT	Filling the cell with titrated NOx before taking the NOx measurement.
NOx_SAMPLE	Reading NO_2 concentration in titrated sample (which is representative of NOx concentration).
AUTOREF	In Auto Reference mode. Sample pulled through Charcoal scrubber.

Board LEDs shown in Figure 5-8, Figure 5-9, and Figure 5-10 also indicate what state the analyzer is in.

Briefly summarized, the Model N500 analyzer first measures NO_2 directly by way of optical absorption to yield a true reading of NO_2 concentration. Next, it uses a precisely-timed pulsation to mix the sample with an excessive concentration of O_3 to create NO_X. The software subtracts the NO_2 concentration from the resulting NO_X concentration to calculate an NO reading. The NO concentration is then corrected for titration efficiency (TE) which is then added to the measured NO_2 value to produce a corrected NO_X measurement.

Pressure transducers monitor the sample pressure and the cell pressure to verify pressure levels, which are used for a variety of important calculations and diagnostics.

6.2. ELECTRONIC OPERATION

The electronic platform is based on a Controller Area Network (CAN) bus modular system. CAN is the central networking system that enables communication among all the parts and facilitates centralized diagnoses of errors, as well as configuration of all the parts. CAN bus technology allows for a uniform cable architecture with interchangeable 6-pin connectors configured for power (5 V and 24 V) and communications (CAN high and CAN low serial lines).

The Mainboard is the main hub, which not only contains the Central Processing Unit (CPU) that communicates with other modules, but also directs power and communication distribution. The Mainboard includes an altitude sensor, a temperature sensor, and the Supervisory Chip.

The Supervisory Chip monitors power and the sensors, and when the front panel Soft Power switch is pressed (see Power Switches, Section 6.2.2), the Supervisory Chip directs the soft power down of the internal components, to safely shut down processes and close connections to prevent damage.

6.2.1. MODULES

Each module consists of its own board controlled by a microprocessor that receives messages from and sends information to the Mainboard on the CAN network. Depending on the signal line, CAN Low or CAN High, the modules can determine whether a message is intended for them and what the priority is, and then act on the applicable messages. These are called “Smart Modules,” which conduct local operations, such as activating the zero/span valves, toggling the NOx/NO_2 valve, or controlling manifold temperature. There is also the Sensor Module; it is comprised of the Optical Bench Unit which has the gas sensor inside the main oven and the CAPS data acquisition (DAQ) board with logic device, microcontroller and LED driver mounted on the outside. The Sensor Module calculates gas concentrations and may command the Smart Modules.

6.2.2. POWER SWITCHES

The front panel Soft Power switch is used to protect the internal components from damage. When the instrument is initially powered on, the Supervisory Chip spins up the internal computer components and places them in operational mode (indicated by LED’s solid-lit state). However, before powering off the instrument, pressing and momentarily holding the solid-lit Soft Power switch tells the Supervisory Chip to put the internal computer components through a soft-shutdown process and into deep sleep mode (indicated by LED’s blinking state) in order to protect them from damage when fully turning off power.

The rear panel Hard Power switch is used to turn on or off the instrument; however, before turning off the instrument, the Soft Power switch must be used first as described above. If there is an unexpected loss of source power while the instrument is running, it will power up in the ON state when source power is restored.

GLOSSARY

TERM	DESCRIPTION/DEFINITION
ASSY	*Assembly*
CAS	*Code-Activated Switch*
CD	*Corona Discharge*, a frequently luminous discharge, at the surface of a conductor or between two conductors of the same transmission line, accompanied by ionization of the surrounding atmosphere and often by a power loss
CE	*Converter Efficiency*, the percentage of the total amount that is actually converted (e.g., light energy into electricity; NO_2 into NO, etc.)
CEM	*Continuous Emission Monitoring*
Chemical elements that may be included in this document:	
CO_2	carbon dioxide
C_3H_8	propane
CH_4	methane
H_2O	water vapor
HC	general abbreviation for hydrocarbon
HNO_3	nitric acid
H_2S	hydrogen sulfide
NO	nitric oxide
NO_2	nitrogen dioxide
NO_X	nitrogen oxides, here defined as the sum of NO and NO_2
NO_y	nitrogen oxides, often called odd nitrogen: the sum of NO_X plus other compounds such as HNO_3 (definitions vary widely and may include nitrate (NO_3), PAN, N_2O and other compounds as well)
NH_3	ammonia
O_2	molecular oxygen
O_3	ozone
SO_2	sulfur dioxide
cm^3	metric abbreviation for *cubic centimeter* (replaces the obsolete abbreviation "cc")
CPU	*Central Processing Unit*
DAC	*Digital-to-Analog Converter*
DAS	*Data Acquisition System*
DCE	*Data Communication Equipment*
DFU	*Disposable Filter Unit*
DHCP	*Dynamic Host Configuration Protocol.* A protocol used by LAN or Internet servers to automatically set up the interface protocols between themselves and any other addressable device connected to the network
DOM	*Disk On Module,* a 44-pin IDE flash drive with up to 128MB storage capacity for instrument's firmware, configuration settings and data
DOS	*Disk Operating System*
DRAM	*Dynamic Random Access Memory*
DR-DOS	*Digital Research DOS*
DTE	*Data Terminal Equipment*
EEPROM	*Electrically Erasable Programmable Read-Only Memory* also referred to as a FLASH chip or drive
ESD	*Electro-Static Discharge*

TERM	DESCRIPTION/DEFINITION
ETEST	*Electrical Test*
Ethernet	a standardized (IEEE 802.3) computer networking technology for local area networks (LANs), facilitating communication and sharing resources
FEP	*Fluorinated Ethylene Propylene* polymer, one of the polymers that Du Pont markets as *Teflon®*
Flash	non-volatile, solid-state memory
FPI	*Fabry-Perot Interface*: a special light filter typically made of a transparent plate with two reflecting surfaces or two parallel, highly reflective mirrors
GFC	*Gas Filter Correlation*
IC	*Integrated Circuit*, a modern, semi-conductor circuit that can contain many basic components such as resistors, transistors, capacitors, etc., in a miniaturized package used in electronic assemblies
IP	*Internet Protocol*
IZS	*Internal Zero Span*
LAN	*Local Area Network*
LCD	*Liquid Crystal Display*
LED	*Light Emitting Diode*
LPM	*Liters Per Minute*
MFC	*Mass Flow Controller*
M/R	*Measure/Reference*
NDIR	*Non-Dispersive Infrared*
MOLAR MASS	the mass, expressed in grams, of 1 mole of a specific substance. Conversely, one mole is the amount of the substance needed for the molar mass to be the same number in grams as the atomic mass of that substance. EXAMPLE: The atomic weight of Carbon is 12 therefore the molar mass of Carbon is 12 grams. Conversely, one mole of carbon equals the amount of carbon atoms that weighs 12 grams. Atomic weights can be found on any Periodic Table of Elements.
NDIR	*Non-Dispersive Infrared*
NIST-SRM	*National Institute of Standards and Technology - Standard Reference Material*
PC	*Personal Computer*
PCA	*Printed Circuit Assembly*, the PCB with electronic components, ready to use
PC/AT	*Personal Computer / Advanced Technology*
PCB	*Printed Circuit Board*, the bare board without electronic component
PFA	*Per-Fluoro-Alkoxy*, an inert polymer; one of the polymers that *Du Pont* markets as *Teflon®*
PLC	*Programmable Logic Controller*, a device that is used to control instruments based on a logic level signal coming from the analyzer
PLD	*Programmable Logic Device*
PLL	*Phase Lock Loop*
P/N (or PN)	*Part Number*
PSD	*Prevention of Significant Deterioration*
PTFE	*Poly-Tetra-Fluoro-Ethylene*, a very inert polymer material used to handle gases that may react on other surfaces; one of the polymers that *Du Pont* markets as *Teflon®*
PVC	*Poly Vinyl Chloride*, a polymer used for downstream tubing
Rdg	Reading

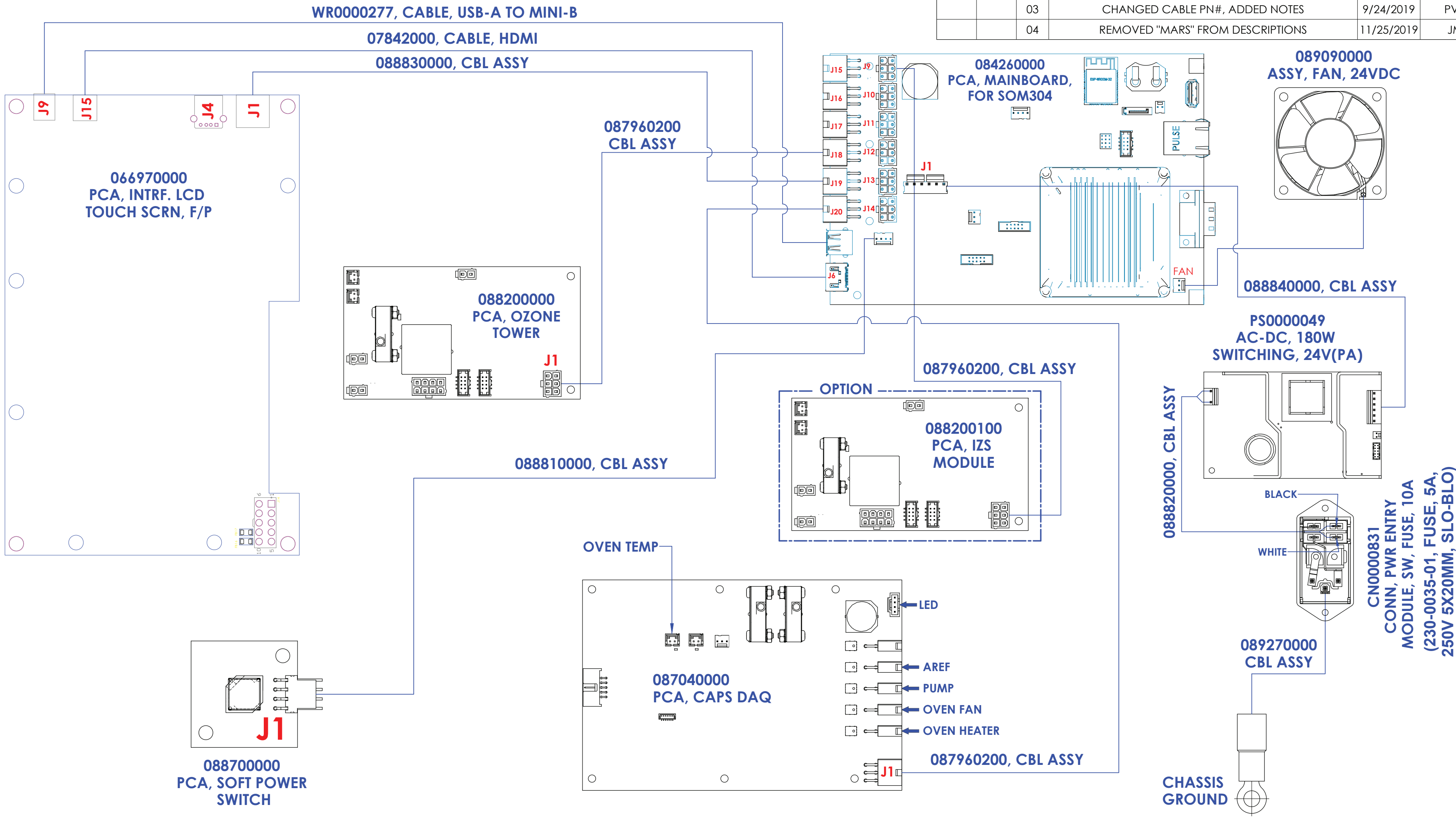
TERM	DESCRIPTION/DEFINITION
RS-232	specification and standard describing a serial communication method between DTE (Data Terminal Equipment) and DCE (Data Circuit-terminating Equipment) devices, using a maximum cable-length of 50 feet
RS-485	specification and standard describing a binary serial communication method among multiple devices at a data rate faster than RS-232 with a much longer distance between the host and the furthest device
SAROAD	*Storage and Retrieval of Aerometric Data*
SLAMS	*State and Local Air Monitoring Network Plan*
SLPM	*Standard Liters Per Minute* of a gas at standard temperature and pressure
STP	*Standard Temperature and Pressure*
TCP/IP	*Transfer Control Protocol / Internet Protocol*, the standard communications protocol for Ethernet devices
TEC	*Thermal Electric Cooler*
TPC	*Temperature/Pressure Compensation*
USB	*Universal Serial Bus*: a standard connection method to establish communication between peripheral devices and a host controller, such as a mouse and/or keyboard and a personal computer or laptop
VARS	*Variables*, the variable settings of the instrument
V-F	*Voltage-to-Frequency*
Z/S	*Zero / Span*

APPENDIX A – MODBUS REGISTERS

ADDR	DESCRIPTION	UNITS
Discrete Inputs		
1	SYS_WARN_CAPS_COM_WARNING	Indicates status of CAPS board communication warning
2	SYS_WARN_CELL_PRESSURE	Indicates status of cell pressure warning
3	SYS_WARN_MANUAL_AREF	Indicates status of manual auto reference warning
4	SYS_WARN_OZONE_PRESSURE	Indicates status of Ozone pressure warning
5	SYS_WARN_OZONE_TOWER_COM_WARNING	Indicates status of Ozone tower communication warning
6	SYS_WARN_RESET	Indicates status of system reset warning
7	SYS_WARN_SAMPLE_FLOW	Indicates status of sample flow warning
8	SYS_WARN_SAMPLE_PRESSURE	Indicates status of sample pressure warning
9	SYS_WARN_SAMPLE_TEMP_WARN	Indicates status of sample temperature warning
10	SYS_WARN_TIME_NOT_SYNCED	Indicates status of time-since warning
11	SYS_WARN_ACAL1_CAL_FAIL	Indicates Auto-Cal Seq 1 failed
12	SYS_WARN_ACAL2_CAL_FAIL	Indicates Auto-Cal Seq 2 failed
13	SYS_WARN_ACAL3_CAL_FAIL	Indicates Auto-Cal Seq 3 failed
Coils		
20	MB_ZERO_CAL_RANGE1	Trigger zero calibration of NO2 range 1
21	MB_SPAN_CAL_RANGE1	Trigger span calibration of NO2 range 1
Input Registers		
0	NO2_SLOPE1	Slope for range 1
4	NO2_OFFSET1	Offset for range 1 in PPB
8	NO2_PRE_CAL_CONC_1	Concentration just prior to last zero/span cal of range #1
12	NO2_CONC	NO2 concentration for range 1
16	NO2_STABILITY	NO2 stability
18	AI_REALTIME_LOSS	Realtime loss value in Mm-1
20	AI_OVEN_TEMP	Oven temperature in degree C
22	AI_OVEN_DUTY_CYCLE	Oven temperature duty cycle
24	AI_MANIFOLD_TEMP	Manifold temperature in degree C
26	AI_MANIFOLD_CYCLE	Manifold temperature duty cycle
28	AI_IZS_TEMP	IZS lamp temperature in degree C
30	AI_IZS_CYCLE	IZS temperature duty cycle
32	AI_SAMPLE_TEMP	Sample temperature in degree C
34	AI_SAMPLE_PRESSURE	Sample pressure in inches Hg-A
36	AI_BOX_TEMP	Box temperature in degree C
42	AI_PHASE_ANGLE	Phase angle value
44	NO_SLOPE1	NO slope for range 1
48	NO_OFFSET1	NO Offset for range 1
52	NO_PRE_CALC_CONC_1	NO concentration for range 1 during zero/span calibration
56	NO_CONC	NO concentration for range 1
60	NO_STABILITY	NO stability
62	NOX_SLOPE1	NOX slope for range 1

ADDR	DESCRIPTION	UNITS
68	NOX_OFFSET1	NOX Offset for range 1
72	NOX_PRE_CALC_CONC_1	NOX concentration for range 1 during zero/span calibration
76	NOX_CONC	NOX concentration for range 1
80	NOX_STABILITY	Concentration stability
Holding Registers		
0	NO2_TARGET_SPAN_CONC_1	NO2 Target span concentration for range #1
4	NOX_TARGET_SPAN_CONC_1	NOX Target span concentration for range #1

REVISION HISTORY					
ZONE	DCN	REV	DESCRIPTION	DATE	APPROVED
		01	INITIAL RELEASE, PROTOTYPE	8/9/2019	PVU
		02	REVISED WIRING, ADDED FAN	8/22/2019	PVU
		03	CHANGED CABLE PN#, ADDED NOTES	9/24/2019	PVU
		04	REMOVED "MARS" FROM DESCRIPTIONS	11/25/2019	JM



PRINTED COPIES OF THIS DOCUMENT ARE UNCONTROLLED

THIRD ANGLE PROJECTION

Use and Disclosure of Data
Information contained herein is classified as EAR99 under the U.S. Export Administration Regulations. Export, reexport or diversion contrary to U.S. law is prohibited.

The information hereon is the property of API and is submitted in strictest confidence for reference only. Unauthorized use by anyone for any other purposes is prohibited. This document or any information contained in it may not be duplicated without proper authorization.

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ARE: FRACTIONS ±1/16 DECIMALS .XX = ±.03 .XXX = ±.010 ANGLES ±0°30'

DO NOT SCALE DRAWING

TREATMENT

FINISH

SIMILAR TO | ACT WT | CALC WT

CONTRACT

APPROVALS		DATE
DRAWN	-	-
CHECKED	-	-
CCB	-	-
ISSUED	-	-

TELEDYNE ADVANCED POLLUTION INSTRUMENTATION
Everywhereyoulook

TITLE
DIAG, INTERCONNECT, CAPS, NOX

SIZE	CAGE CODE	DWG NO	REV
D	1JZF4	08931	04
SCALE 1:1	FORM ENF0029 RevE	SHEET 1 OF 1	