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Report on the performance test of the N200 ambient air quality measuring system manufactured by Teledyne API for the components NO, NO_2 and NO_x

TÜV Report: 936/21255654/A
Cologne, 25 January 2023

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Report on the performance test of the N200 ambient air quality measuring system manufactured by Teledyne API for the components NO, NO2 and NOx

AMS designation: N200

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

Test period: March 2022 to August 2022

Date of report: 25 January 2023

Report Number: 936/21255654/A

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Scope of report:

Report:		134	Pages
Manual	From page	145	
Manual	with	199	Pages
Total		344	Pages

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1. Summary and certification proposal

1.1 Summary Overview

On behalf of Teledyne API, TÜV Rheinland Energy GmbH carried out the performance testing for the N200 ambient air measuring system for the components NO, NO_2 and NO_x. Testing was carried out in compliance with the following norms / standards and requirements:

- VDI Guideline 4202 Part 1: 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, November 2012

The N200 analyser measures the components NO, NO_2 and NO_x using chemiluminescence principle. This measuring principle conforms to the EU reference method. The tests were performed in a TÜV Rheinland Energy GmbH laboratory and in a three-month field test in 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 recommends 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:

N200 for NO, NO_2 und NO_x

Manufacturer:

Teledyne API, San Diego, USA

Field of application:

For the continuous measurement 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. 1.9.0

Restrictions:

None

Note:

1. This report on the performance test is available online at www.qal1.de.
2. The AMS is approved for an ambient temperature range of 0 - 45 °C.
3. The N200 measuring system can be equipped with both an internal and an external pump.
4. The N200 measuring system can be equipped with a standard Teflon particle filter with a pore size of 5 µm and a diameter of 47 mm as well as with a DFU filter cartridge with a pore size of 0.01 µm.

Test Report:

TÜV Rheinland Energy GmbH, Cologne
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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 front of the instrument.	yes	34
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	35
7.3.3 Easy maintenance	It should be possible to perform the necessary maintenance works on the AMS without major overheads, preferably from outside.	Maintenance work can be carried out externally with standard tools and reasonable effort.	yes	36
7.3.4 Functional check	Special instruments for this purpose are to be considered as belonging to the equipment, to be used in the corresponding sub-tests and to be evaluated.	The tested measuring system does not have internal devices for operating the functional check.	not applicable	37
7.3.5 Set-up times and warm-up times	The instruction manual shall include specifications in this regard.	The set-up and warm-up times are specified in the operating instructions. The manufacturer's specifications are accurate.	yes	38
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	39
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	40
7.3.8 Data output	The output signals shall be provided digitally and/or as analogue signals.	The measured signals are available both analogue (0 – 20 mA, 4 – 20 mA or 0 – 1V,0 – 5 V, 0 – 10 V) and digitally (via TCP/IP, RS 232, USB).	yes	41
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	The digital measured value transmission functions correctly and is protected against unauthorised access by password protection.	yes	42

	unauthorised use.			

Performance criterion	**Requirement**	**Test result**	**Satisfied**	**Page**
7.3.10 Data transmission protocol	Shall meet the requirements stipulated in Table 1 of VDI Guideline 4202 part 1.	The measuring system has a Modbus Bayern/Hessen transmission protocol installed as standard. Measured and status signals are transmitted correctly. The configuration is listed in the manual in Appendix A.2 from page 194.	yes	43
7.3.11 Measuring range	The upper limit of measurement shall be greater or equal to the upper limit of the certification range.	A measuring range of 0 – 500 µg/m³ for NO_2 and 1200 µg/m³ for NO is set as standard. Supplementary measuring ranges up to 0 – 20 ppm are possible. The measuring system's upper limit of measurement exceeds the upper limit of the certification range in each case.	yes	44
7.3.12 Negative output signals	Shall not be suppressed (live zero).	The measuring system also provides negative output signals.	yes	45
7.3.13 Failure in the mains voltage	Uncontrolled emission of operation and calibration gas shall be avoided; instrument parameters shall be secured by buffering against loss; when mains voltage returns, the instrument shall automatically reach the operation mode and start the measurement.	On return of mains voltage, the instrument returns to normal operating mode and after a warm-up phase automatically resumes measuring.	yes	46
7.3.14 Operating states	Must be able to be monitored by status signals that can be transmitted telemetrically.	The measuring system provides various ports to ensure comprehensive monitoring and control via an external computer.	yes	47
7.3.15 Switch-over	Switch-over between measurement and functional check and/or calibration shall be possible telemetrically.	As a rule, all necessary work for functional checks can be monitored and controlled directly on the instrument or by telemetric remote control.	yes	48
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	49

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.	The test was carried out using the performance criteria and requirements of VDI 4202 Part 1 (2018) and EN 14211 (2012).	yes	50
7.4.2 Test requirements	Has to comply with the requirements set out in VDI standard 4202-1:2018.	The test was carried out using the performance criteria and requirements of VDI 4202 Part 1 (2018) and EN 14211 (2012).	yes	51
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.	The test was carried out using the performance criteria and requirements of VDI 4202 Part 1 (2018) and EN 14211 (2012).	yes	69
7.5.2 Location for the field test	The monitoring station for the field test is to be chosen according to the requirements of the 39th BImSchV such that the expected concentrations of the measured components 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	70
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	71
Section 8.5 provides a summary of the evaluation of performance characteristics determined in the field.				

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 31 sec for NO and 34 sec for NO2. For unit 2 it was 30 sec for NO and 36 sec for NO2.	yes	79
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 0.51 nmol/mol for instrument 1; for instrument 2, it was -0.12 nmol/mol. For NO, the value for the short-term drift at span point was -0.87 nmol/mol for instrument 1; for instrument 2, it was 1.14 nmol/mol.	yes	84
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 0.28 nmol/mol for instrument 1; for instrument 2 it was 0.25 nmol/mol. Repeatability standard deviation at reference point was 0.56 nmol/mol for instrument 1 and 0.35 nmol/mol for instrument 2.	yes	88
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.	The deviation from the linear regression line for instrument 1 is -0.24 nmol/mol at zero point and no more than 0.40% of the nominal value for concentrations above zero. The deviation from the linear regression line for instrument 2 was 0.48 nmol/mol at zero point and no more than 1.07% of the nominal value for concentrations above zero.	yes	91
8.4.7 Sensitivity coefficient of sample gas pressure	The sensitivity coefficient of sample gas pressure shall be ≤ 8.0 nmol/mol/kPa.	For NO, the sensitivity coefficient of sample gas pressure was 0.82 nmol/mol/kPa for instrument 1; for instrument 2 it was 0.86 nmol/mol/kPa.	yes	96

Performance criterion	Requirement	Test result	Satis-fied	Page
8.4.8 Sensitivity coefficient of sample gas temperature	The sensitivity coefficient of sample gas temperature shall be ≤ 3.0 nmol/mol/K.	The sensitivity coefficient of the sample gas temperature was 0.05 nmol/mol/K for instrument 1 and 0.09 nmol/mol/K for instrument 2.	yes	98
8.4.9 Sensitivity coefficient of surrounding temperature	The sensitivity coefficient of the surrounding temperature shall be ≤ 3.0 nmol/mol/K.	The sensitivity coefficient of the surrounding temperature bst did not exceed the performance criterion specified at 3.0 nmol/mol/K. For the purpose of the uncertainty calculation, the largest value bst is used for both instruments. For NO, this was 0.581 nmol/mol/K for instrument 1 and 0.269 nmol/mol/K for instrument 2.	yes	100
8.4.10 Sensitivity coefficient of electrical voltage	The sensitivity coefficient of electrical voltage shall not exceed 0.30 nmol/mol/V.	At no test item did the sensitivity coefficient of electrical voltage bv exceed the value of 0.30 nmol/mol/V specified in standard EN 14211. For the purpose of the uncertainty calculation, the largest bv is used for both instruments. For NO, this is 0.00 nmol/mol/V for instrument 1 and 0.01 nmol/mol/V for instrument 2.	yes	103
8.4.11 Interferents	Interfering components at zero and at the NO concentration c_t (500 ± 50 nmol/mol). Deviations for interferents H_2O, CO_2 and NH_3 shall not exceed 5.0 nmol/mol.	At zero point the results for the interference were 1.20 nmol/mol (AMS 1) and 1.00 nmol/mol (AMS 2) for H2O, -0.60 nmol/mol (AMS 1) and -0.60 nmol/mol (AMS 2) for CO2, and finally 0.00 nmol/mol (AMS 1) and 0.00 nmol/mol (AMS 2) for NH3. For the cross-sensitivity at the limit value ct, the values were -2.40 nmol/mol for instrument 1 and -1.20 nmol/mol for instrument 2 for H2O, 1.60 nmol/mol for instrument 1 and 0.40 nmol/mol for instrument 2 for CO2, and 1.60 nmol/mol for instrument 1 and 2.00 nmol/mol for NH3.	yes	105
8.4.12 Averaging test	The averaging effect shall not exceed 7% of the measured value.	The performance criterion of EN 14211 for the averaging test was fully complied with at 0.9 % and -0.3 % respectively. .	yes	108

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 of EN 14211 was fully met with a maximum deviation of -0.19 % and -0.03 % respectively.	yes	111
8.4.14 Converter efficiency	The converter efficiency shall be at least 98%.	The performance criterion of EN 14211 was fully met with a converter efficiency of at least 99.2 %.	yes	113
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 ca. 1.5 s.	yes	113
8.5 Determination of the performance characteristics during the field test according to EN 14211				
8.5.4 Long-term drift	The long-term drift at zero point shall not exceed ≤ 5.0 nmol/mol. Long-term drift at span level shall not exceed 5% of the certification range.	Maximum long-term drift at zero point $D_{l,z}$ for NO was at 0.84 nmol/mol for instrument 1 and 0.96 nmol/mol for instrument 2. Maximum long-term drift at span point $_{Dl}$,s for NO was at -1.19% for instrument 1 and -1.27% for instrument 2.	yes	117
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. A check of the zero and span point must be carried out at least every 14 days in accordance with EN 14211.	yes	123
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 NO_2 under field conditions was 3.57 % related to the mean value over the duration of the field test of 3 months. Thus, the requirements of EN 14211 are satisfied.	yes	120
8.5.7 Period of availability of the analyser	Availability of the analyser shall be at least 90%.	The availability was at 100%. Thus, the requirement of EN 14211 is satisfied.	yes	124

2. Task definition

2.1 Nature of the test

On behalf of Teledyne API, TÜV Rheinland Energy GmbH carried out the performance testing for the N200 ambient air measuring system. 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 N200 measuring system measures the components NO, NO_2 and NO_x using the chemiluminescence method.

The performance test was carried out on the basis of the current standards / guidelines for performance testing, taking into account the latest developments.
The test was carried out in compliance with the following standards / norms:

- 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, November 2012

3. Description of the AMS tested

3.1 Measuring principle

The measurement principle is based on the detection of chemiluminescence occurring during the reaction of nitrogen oxide (NO) with ozone (O_3). This reaction takes place in two steps.

In the first step, a molecule of NO collides with a molecule of O_3 and produces a molecule of oxygen (O_2) and a molecule of nitrogen dioxide (NO_2) in a chemical reaction. Part of the NO_2 retains a certain amount of excess energy from the collision and as a result remains in an excited state. This means that one electron of the NO_2 molecule remains in a higher energy state than normal.

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

Thermodynamics requires that systems seek the lowest stable energy state; consequently the NO_2 molecule will quickly return to its ground state in the next step. In doing so, it releases the excess energy in the form of a light quantum (hv).

$$NO_2^* \rightarrow NO_2 + hv$$

If all factors are constant, the relationship between the amount of NO present in the reaction chamber and the light emitted by the reaction is very linear. More NO produces more light that can be measured with a light-sensitive sensor.

The analyser uses a special vacuum tube, the photomultiplier tube (PMT), to detect the amount of light generated from the NO and O_3 reaction in the reaction chamber. Photons enter the PMT and strike a negatively charged photocathode, causing electrons to be emitted. These electrons are accelerated by a high voltage and multiplied by a series of similar acceleration steps (dynodes) until a usable current signal is produced. The more light there is (in this case photons from the chemiluminescence reaction described above), the more electricity is generated. So the more NO there is in the reaction chamber, the greater the current generated by the PMT. The current generated by the PMT is converted to a voltage and transmitted to the analyser's CPU to calculate a measured signal.

3.2 AMS scope and set-up

The N200 Nitric Oxide Analyser determines the concentration of Nitric Oxide (NO), Total Nitric Oxide (NO_x, the sum of NO and NO_2) and Nitric Dioxide (NO_2) of a sample drawn into the instrument. For this purpose, sample and calibration gases must be provided at ambient air pressure to ensure a constant gas flow through the reaction chamber. In the reaction chamber, the sample gas is exposed to ozone (O_3), which triggers a light-emitting chemical reaction (chemiluminescence). The instrument measures the amount of chemiluminescence to determine the NO content in the sample gas. A catalytic-reactive converter converts any NO_2 in the sample gas into NO, which is then displayed as NO_x, including the NO in the sample gas. NO_2 is calculated as the difference between NO_x and NO.

The only gas that is actually measured in the N200 is NO. Any NO_2 contained in the gas is not detected because NO_2 does not react with O_3 in order to be exposed to chemiluminescence. To measure the concentration of NO or NO_x, the N200 periodically switches the sample gas flow through a converter cartridge filled with molybdenum chips and heated to a temperature of 315°C. The heated molybdenum reacts with the NO_2 in the sample gas and converts it to NO. After the NO_2 in the sample gas has been converted to NO, it is passed through the reaction chamber where it is subjected to the chemiluminescence reaction.

Figure 1: N200 Analysers

By converting the NO_2 in the sample gas to NO, the analyser can measure the total NO_x (NO + NO_2) content in the sample gas. By switching the NO_2 converter on and off in and out of the gas stream at 6 - 10 second intervals, the analyser can more or less continuously measure both NO and total NO_x levels. The NO_2 concentration is ultimately not measured, but calculated by subtracting the known NO content from the sample gas from the known NO_x content.

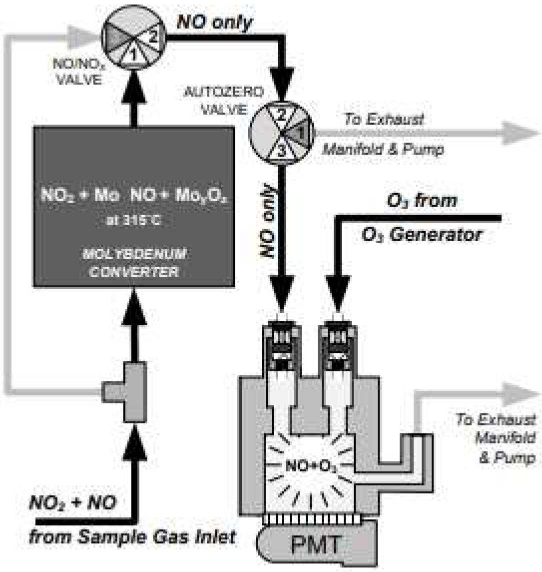


Figure 2: NO_2 conversion principle

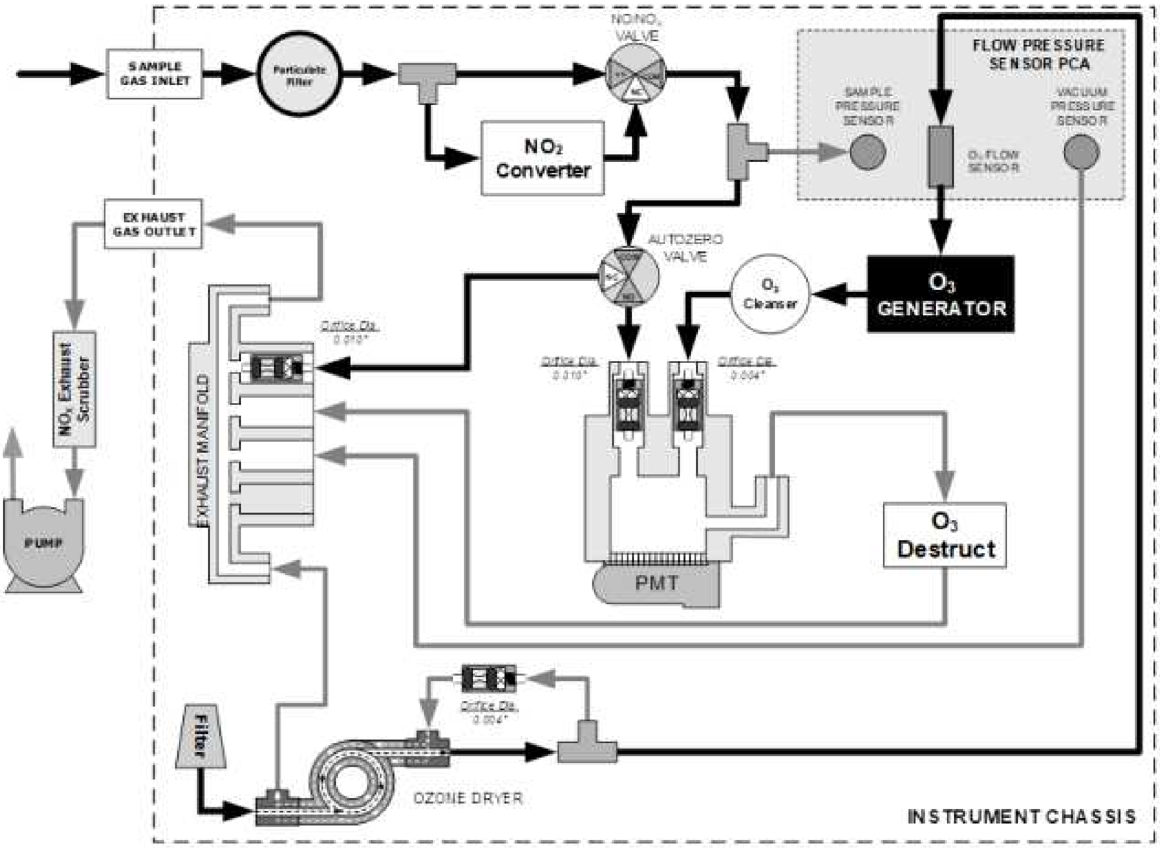


Figure 3: Pneumatic diagram N200

Components of the analyser

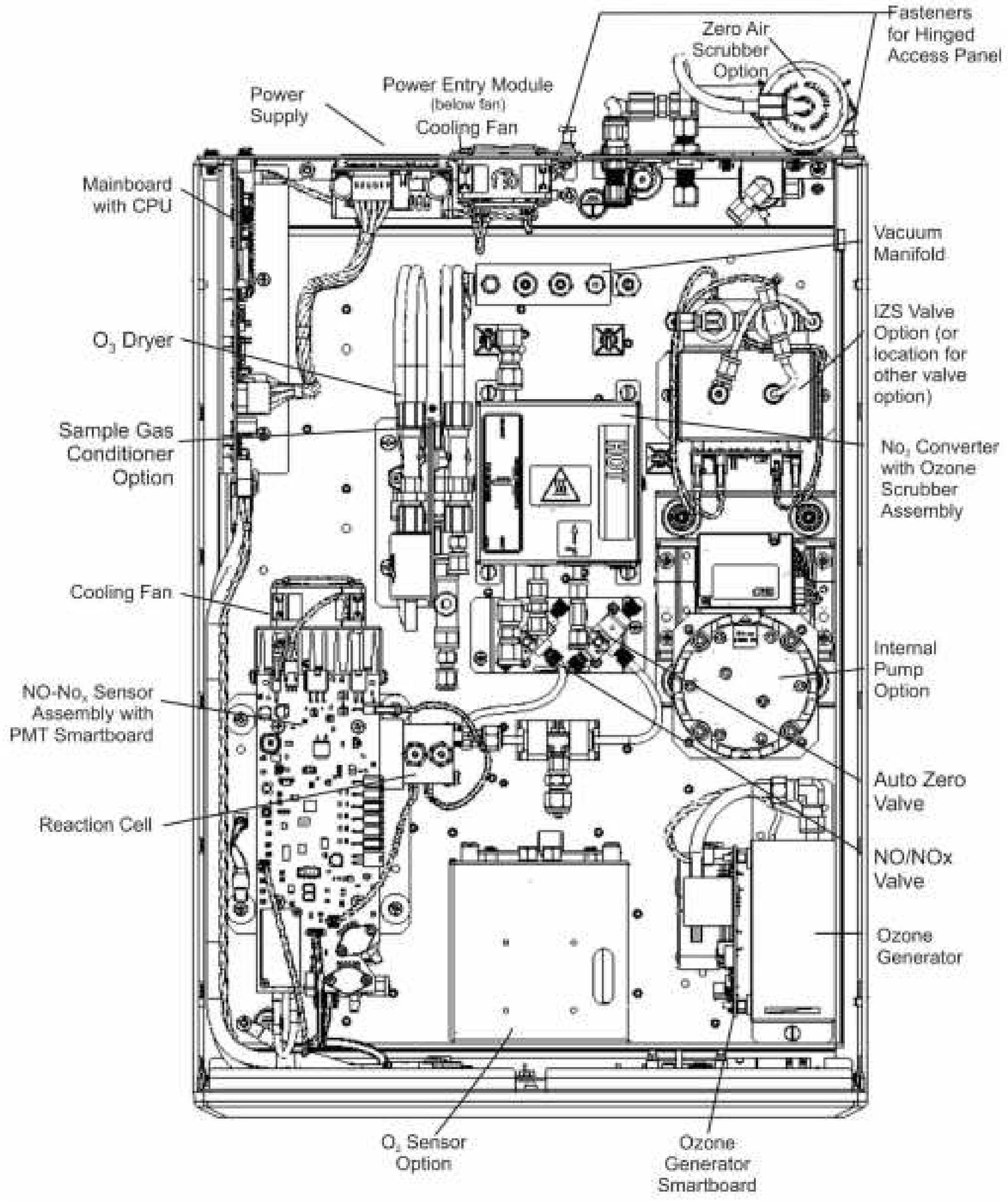


Figure 4: Set-up of the N200 analyser

Table 2 lists a number of important technical specifications of the N200.

Table 2: Technical data N200 (manufacturer's data)

Measured range:	Max 0 – 20 ppm (selectable)
Units:	ppb, ppm, mg/m³ or µg/m³
Measured compounds:	NO, NO_2 and NO_x
Sample flow rate:	~0.5 l/min (during the test)
Outputs:	• Ethernet TCP/IP • Serial interface, RS232 • 0 – 5/10 Volt analogue • 4 – 20 mA analogue • USB
Input voltage:	230 V or 115 V 50 Hz or 60 Hz
Power:	ca. 90 W; maximum 190 W
Dimensions (l x w x h) / weight:	597 x 432 x 178 mm / ~ 18 kg

3.3 AMS adjustment

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

The N200 analyser firmware processes sample concentration data through 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 stable 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.

3.4 Alternative assemblies

Particle filter

The N200 measuring system has a particle filter directly behind the sample gas inlet. The particle filter is located on a panel secured with two screws on the back of the AMS. The manufacturer supplies the measuring system with two different types of filters.

The measuring system is available with a standard Teflon particle filter with a pore size of 5 µm and a diameter of 47 mm. This type of filter has been used for many years in Teledyne ambient air measuring systems.

Alternatively, it is possible to equip the N200 measuring system with a DFU filter cartridge with a pore size of 0.01 µm (a so-called long-life filter). For this filter, the manufacturer specifies a replacement interval of up to 6 months. The replacement interval for the particle filter is of course dependent on the dust load at the installation site and must be determined individually for each measuring point. The filter can be changed within a few minutes with simple tools for both types of filter.

Figure 5: DFU filter (left) and 47 mm round filter (right)

The entire performance test was carried out with the DFU filter. The filter was not replaced during the field test or between the laboratory and field test.

Following the last long-term drift test in the field test, the DFU filter was exchanged for the 47 mm filter. The test gas task was then repeated. The measuring system showed comparable measured results with the new filter. The results are shown in Appendix 4.

The N200 measuring system can be equipped with a DFU particle filter as well as with a 47 mm round filter. The replacement interval for the particle filter is of course dependent on the dust load at the installation site and must be determined individually for each measuring point.

Pump

The manufacturer offers two different types of pumps for the N200 measuring system.

- An internal unregulated pump (HD Non-PID). This type of pump always runs at 100 % capacity. The nominal flow rate is set by a built-in critical nozzle. If the flow deviates more than 10 % from the nominal value, an operational status signal is generated. The critical nozzle is located in the pump and thus behind the measuring cell.
- An external unregulated pump (HD Non-PID). This type of pump always runs at 100 % capacity. The nominal flow rate is set by a built-in critical nozzle. If the flow deviates more than 10 % from the nominal value, an operational status signal is generated. The critical nozzle is located in the pump and thus behind the measuring cell.

Both pump types are controlled by the same control board.

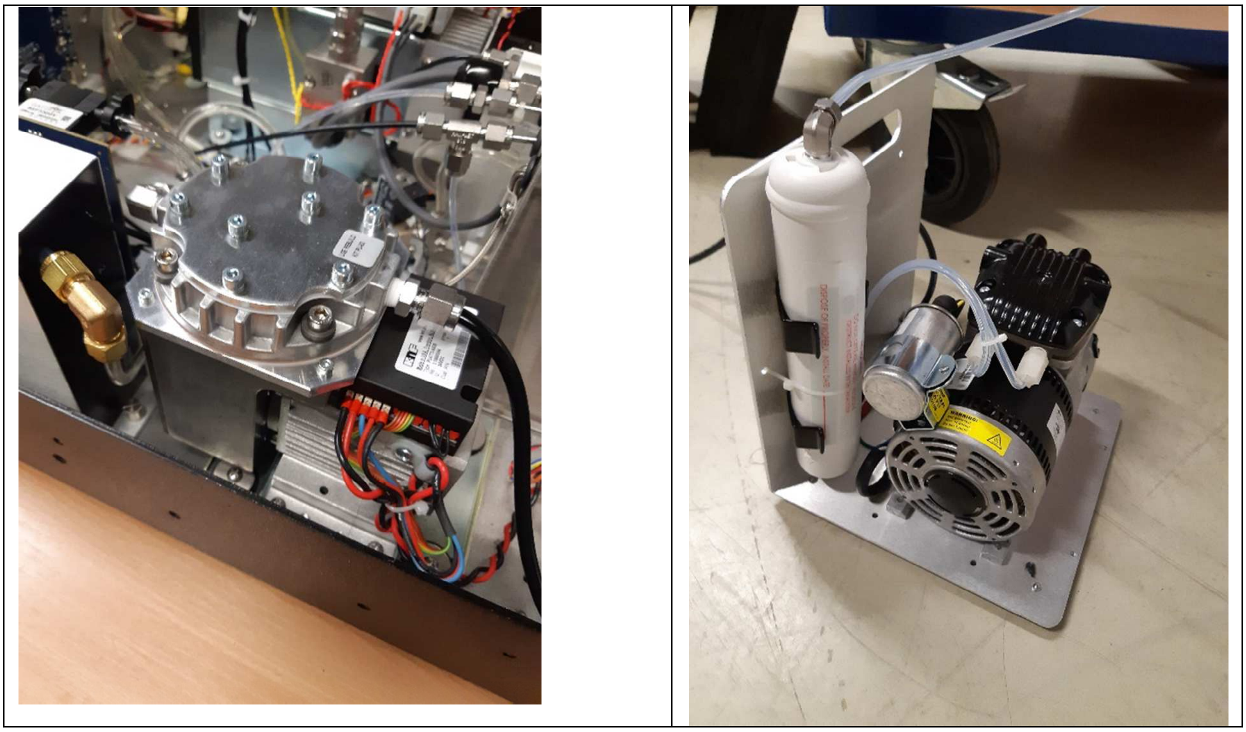


Figure 6: Internal pump (left) and non-external pump (right)

The entire performance test was carried out with the internal pump.

After completion of the field test, the internal pump was disconnected and replaced with an external pump. Subsequently, the test point "Sensitivity to sample gas pressure" was carried out with the alternative, external pump type.
The above-mentioned test point was also fulfilled by the measuring system when using the external pump type. Results are shown in Appendix 3.

The N200 measuring system can be equipped with both an internal and external pump.

4. Test programme

4.1 General remarks

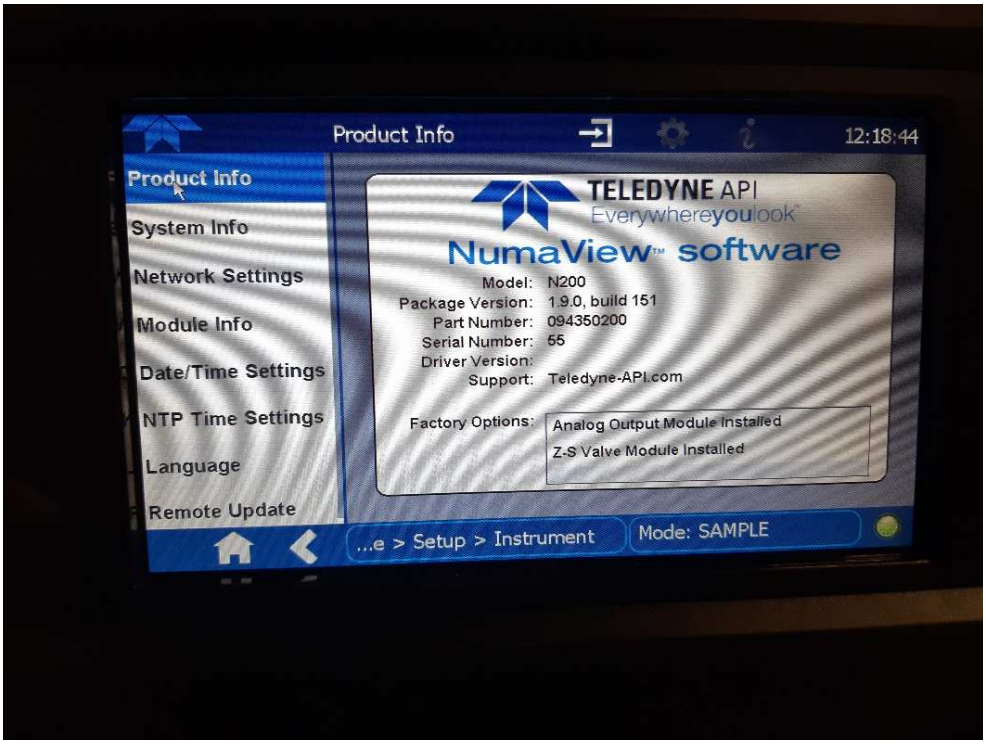
Testing was carried out on two identical N200 systems with the serial numbers

Instrument 1:	SN 55 and
Instrument 2:	SN 56

Testing was performed with software version Rev. 1.9.0

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 minimum requirements according to the relevant standards ([1, 2, 3]) including chapter number and wording.



Model: N200
Package Version: 1.9.0, build 151
Part Number: 094350200
Serial Number: 55
Driver Version:
Support: Teledyne-API.com
Factory Options: Analog Output Module Installed
Z-S Valve Module Installed
Mode: SAMPLE

Figure 7: Software version for the N200 test instruments

4.2 Laboratory test

The laboratory test was carried out with two identical instruments, type N200, with serial numbers S/N: 55 and SN: 56. 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

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 according to EN 14211 and VDI 4202-1 was carried out with two identical N200 measuring systems from 16.05.2022 to 22.08.2022. The instruments used were identical to those used for laboratory testing. The serial numbers were:

Instrument 1:	SN 55
Instrument 2:	SN 56

The following test programme was determined for the field test:

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

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 8: Measuring station for conducting the field test

The measuring systems 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 instruments made 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 9: N200 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 for the purpose of testing. The specified test gases were used during the entire test and, where necessary, were diluted with the help of a (Hovacal) mass flow controller.

The test gas bottle SN: 2732496 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:	**198.5 ppb in N_2**
Number of test gas cylinder:	16953 (Bottle SN: 2732496)
Manufacturer/manufacturing date:	Linde / 16.04.2021
Stability guarantee / certified:	12 months
Checking of the certificate by / on:	14.07.2021 / UBA Langen Calibration certificate No. 025-2021
Measurement uncertainty as per calibration certificate:	+/- 4.0 nmol/mol
Test gas NO:	**2.00 ppm in N_2**
Number of test gas cylinder:	17014
Manufacturer/manufacturing date:	Nippon Gases / 14.01.2021
Stability guarantee / certified:	24 months
Certificate checked by:	Own laboratory
Rel. uncertainty according to certificate:	5%
Test gas NO_2:	**48.6 mg/m³ in N_2**
Number of test gas cylinder:	16970
Manufacturer/manufacturing date:	Nippon Gases / 17.03.2021
Stability guarantee / certified:	24 months
Certificate checked by:	Own laboratory
Rel. uncertainty according to certificate:	2%

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 front of the instrument.

6.5 Assessment

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

Criterion satisfied? yes

6.6 Detailed presentation of test results

Figure 10 shows the measuring system with integrated measured value display.

Figure 10: N200 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

It was 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

The functionality of the separate test gas inlet is shown under point:

7.1 8.4.13 Difference sample/calibration port

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. Check 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. Check the particle filter for the test gas inlet. The frequency at which the particle filter needs to be replaced depends on the dust concentrations in ambient air.

6.5 Assessment

Maintenance work can be carried out externally with standard tools and reasonable effort.

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

Operating manual

6.3 Testing

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

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

6.4 Evaluation

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

External monitoring of the zero and span 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

Operating 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. Since the N200 is a compact analyser, the set-up time is mainly determined by the following tasks:

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

Commissioning and changing positions in the laboratory on various occasions (installation in/removal from the climatic chamber) as well as the installation at the field test location resulted in a set-up time of ~30 minutes. Information on the set-up time can be found in the manual in chapter 2.3. on page 23.

When switched on from a completely cold state, the unit 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 52).

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

The set-up and warm-up times are specified in the operating instructions. The manufacturer's specifications are accurate.

It is possible to operate the measuring system at different locations with limited effort. The set-up time is approx. 0.5 - 1 hour and the warm-up time is 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 over 24 h 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 45 °C.

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

The power consumption of the system is specified by the manufacturer as 55 W (plus 25 W for the internal pump). During start-up (warm-up) a short-term consumption of 190 W was recorded. In normal operation, the consumption is approx. 80 watts, as stated.

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 operating 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 a touch panel or via a PC connected to the measuring system directly or via a network.

The system has an internal function (password protection) against unintentional or unauthorised adjustment. It is only possible to change parameters or adjust the measuring system after entering the password.

6.4 Evaluation

Parameters which have an influence on the measurement properties of the system can only be changed after entering the correct password, both when operating via the display and via the external PC.

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, Selectable concentration range
Digital:	RS232, USB, digital inputs and outputs, TCP/IP network

6.5 Assessment

The measured signals are available both analogue (0 – 20 mA, 4 – 20 mA or 0 – 1V,0 – 5 V, 0 – 10 V) and digitally (via TCP/IP, RS 232, USB).

The use of additional measuring and peripheral devices is possible via the respective connection ports on the instruments.

Criterion satisfied? yes

6.6 Detailed presentation of test results

Not required for this performance criterion.

6.1 7.3.9 Digital interface

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

6.2 Equipment

PC

6.3 Testing

The measuring system provides the following transmission routes: Modbus, RS232. The measuring system also has the option of outputting analogue signals (optional).

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

The digital measured value transmission functions correctly and is protected against unauthorised access by password protection.

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 transmission protocol as standard. Other data transfer protocols are available in consultation with the manufacturer.

6.4 Evaluation

The measuring system has a Modbus Bayern/Hessen transmission protocol installed as standard. Other data transfer protocols are available in consultation with the manufacturer. Measured and status signals are transmitted correctly.

6.5 Assessment

The measuring system has a Modbus Bayern/Hessen transmission protocol installed as standard. Measured and status signals are transmitted correctly. The configuration is listed in the manual in Appendix A.2 from page 194.

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

It was checked whether the upper limit of the measuring range for the measuring system is greater than or equal to the upper limit of the certification range.

6.4 Evaluation

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

Maximum possible measuring range:	20 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

A measuring range of 0 – 500 µg/m³ for NO_2 and 1200 µg/m³ for NO is set as standard. Supplementary measuring ranges up to 0 – 20 ppm are possible.

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

Criterion satisfied? yes

6.6 Detailed presentation of test results

Standard VDI 4202, Part 1 as well as the standard EN 14211 contain the following minimum requirements for the certification ranges of continuous ambient air quality measuring instruments 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 using 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

It was tested in the laboratory as well as in the field whether the measuring system can also output negative measured values.

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

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

Criterion satisfied? yes

6.6 Detailed presentation of test results

Not applicable.

6.1 7.3.14 Operating states

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

6.2 Equipment

Computer for data acquisition

6.3 Testing

The measuring system has various interfaces such as RS232, 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 telemetric data transmission, configuration settings can be made and the analyser display can be shown on the PC. 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

As a rule, all necessary work for functional checks can be monitored and controlled directly on the instrument 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 the 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.

Testing was performed with software version Rev. 1.9.0

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 7 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 described in section 8.4.

6.2 Equipment

Not required for this performance criterion.

6.3 Testing

The test was carried out using the performance criteria and requirements of VDI 4202 Part 1 (2018) and EN 14211 (2012).

6.4 Evaluation

Not applicable.

6.5 Assessment

The test was carried out using the performance criteria and requirements of VDI 4202 Part 1 (2018) and 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 settings have to be recorded 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

The test was carried out using the performance criteria and requirements of VDI 4202 Part 1 (2018) and EN 14211 (2012).

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 supplied with the systems. The entire performance test was carried out with the DFU filter (see chapter 3.4). The filter was not replaced during the field test or between the laboratory and field test.

The entire test was performed with the internal pump.

As described in section 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

The test was carried out using the performance criteria and requirements of VDI 4202 Part 1 (2018) and 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). Please therefore refer 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). Please therefore refer 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). Please therefore refer 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 analytical function describing the relationship between the measured values and the desired values shall be linear.
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). Please therefore refer 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 of 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 of sample gas pressure in accordance with standard EN 14211 (2012). Please therefore refer to chapter 7.1 8.4.7 Sensitivity coefficient of sample gas pressure.

6.4 Evaluation

See chapter 7.1 8.4.7 Sensitivity coefficient of sample gas pressure

6.5 Assessment

See chapter 7.1 8.4.7 Sensitivity coefficient of 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 of 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 of sample gas temperature in accordance with standard EN 14211 (2012). Please therefore refer to chapter 7.1 8.4.8 Sensitivity coefficient of sample gas temperature.

6.4 Evaluation

See chapter 7.1 8.4.8 Sensitivity coefficient of sample gas temperature.

6.5 Assessment

See chapter 7.1 8.4.8 Sensitivity coefficient of 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 of 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). Please therefore refer to chapter 7.1 8.4.9 Sensitivity coefficient of surrounding temperature.

6.4 Evaluation

See chapter 7.1 8.4.9 Sensitivity coefficient of surrounding temperature

6.5 Assessment

See chapter 7.1 8.4.9 Sensitivity coefficient of surrounding temperature

Criterion satisfied? yes

6.6 Detailed presentation of test results

Not applicable in this instance.

6.1 7.4.10 Sensitivity coefficient of 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 of electrical voltage in accordance with standard EN 14211 (2012). Please therefore refer to chapter 7.1 8.4.10 Sensitivity coefficient of electrical voltage.

6.4 Evaluation

See chapter 7.1 8.4.10 Sensitivity coefficient of electrical voltage

6.5 Assessment

See chapter 7.1 8.4.10 Sensitivity coefficient of 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 reference point. A value c_t at 70% to 80% of the upper limit of the certification range shall be used as reference point.

6.2 Equipment

Not applicable

6.3 Testing

Performing and evaluating cross-sensitivity corresponds exactly to determining interferents in accordance with standard EN 14211 (2012). Please therefore refer to chapter 7.1 8.4.11 Interferents.

6.4 Evaluation

See chapter 7.1 8.4.11 Interferents.

6.5 Assessment

See chapter 7.1 8.4.11 Interferents.

Criterion satisfied? yes

6.6 Detailed presentation of test results

Not applicable in this instance.

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 time period for 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 gas 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 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 following applies differently for NO_x measuring instruments

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

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

Where:

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

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

C^{av}_{var} 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 a step change of the NO concentration was applied 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 4: Results of the averaging test for NO

	requirement	device 1		device 2	
averaging effect E_{av} [%]	≤ 7%	0,9	✓	-0,3	✓

This results in the following averaging effects for NO:

System 1: 0.9%

System 2: -0.3 %

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

Table 5: Results of the averaging test for NO_2

	requirement	device 1		device 2	
averaging effect E_{av} [%]	≤ 7%	2,3	✓	2,4	✓

This results in the following averaging effects for NO_2:

System 1: 2.3%

System 2: 2.4%

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 6 and Table 7 the individual results of the averaging effect test are shown.

Table 6: Results of the averaging test for NO

		device 1	device 2
	time	[nmol/mol]	[nmol/mol]
average constant concentration $C_{av,c}$	09:06:00	614,2	613,4
	till		
	09:25:00		
average variable concentration $C_{av,c}$	09:26:00	299,5	309,9
	till		
	09:45:00		

		device 1	device 2
	time	[nmol/mol]	[nmol/mol]
average constant concentration $C_{av,c}$	09:58:00	603,8	603,3
	till		
	10:17:00		
average variable concentration $C_{av,c}$	10:18:00	300,2	306,6
	till		
	10:37:00		

		device 1	device 2
	time	[nmol/mol]	[nmol/mol]
average constant concentration $C_{av,c}$	10:47:00	602,7	601,9
	till		
	11:06:00		
average variable concentration $C_{av,c}$	11:07:00	302,0	295,8
	till		
	10:26:00		

Table 7: Results of the averaging test for NO_2

		device 1	device 2
	time	[nmol/mol]	[nmol/mol]
average constant concentration $C_{av,c}$	09:06:00	214,8	214,6
	till		
	09:25:00		
average variable concentration $C_{av,c}$	09:26:00	216,3	211,1
	till		
	09:45:00		

		device 1	device 2
	time	[nmol/mol]	[nmol/mol]
average constant concentration $C_{av,c}$	09:58:00	217,5	217,1
	till		
	10:17:00		
average variable concentration $C_{av,c}$	10:18:00	210,1	218,1
	till		
	10:37:00		

		device 1	device 2
	time	[nmol/mol]	[nmol/mol]
average constant concentration $C_{av,c}$	10:47:00	215,1	214,3
	till		
	11:06:00		
average variable concentration $C_{av,c}$	11:07:00	205,8	201,4
	till		
	11:26:00		

6.1 7.4.13 Difference between sample and calibration port

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

6.2 Equipment

Not applicable

6.3 Testing

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). Please therefore refer to chapter 7.1 8.4.11 Interferents.

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). Please therefore refer to chapter 7.1 8.4.14 Converter efficiency.

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). Please therefore refer to chapter 7.1 8.4.14 Residence time in the analyser.

6.4 Evaluation

See chapter 7.1 8.4.14 Residence time in the analyser

6.5 Assessment

See chapter 7.1 8.4.14

Criterion satisfied? yes

6.6 Detailed presentation of test results

Not applicable in this instance.

6.1 7.5 Requirements on performance characteristics for testing in the field

6.1 7.5.1 General requirements

The performance characteristics which shall be determined during testing in the field and their related performance criteria for measured components according to 39. BImSchV are given in Table A1 of VDI 4202-1 (2018).

The certification range for other components is to be defined. Performance criteria are to be defined by drawing from Table A1 of VDI 4202-1 (2018) These definitions shall be cleared with the relevant body before testing.

The determination of the performance characteristics shall be done according to the procedures de-scribed in Section 8.5 of VDI 4202-1 (2018).

6.2 Equipment

Not required for this performance criterion.

6.3 Testing

The test was carried out using the performance criteria and requirements of VDI 4202 Part 1 (2018) and EN 14211 (2012).

6.4 Evaluation

Not applicable.

6.5 Assessment

The test was carried out using the performance criteria and requirements of VDI 4202 Part 1 (2018) and 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 settings have to be recorded 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 instrument has an auto-scaling or self-correction function and it is regarded as a "normal operating condition", it shall be operational during the field test. The magnitude of the self-correction has to be available to the testing 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). Please therefore refer 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). Please therefore refer 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). Please therefore refer 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). Please therefore refer to chapter 7.1 8.5.7 Period of availability of the analyser.

6.4 Evaluation

See chapter 7.1 8.5.7 Period of availability of the analyser

6.5 Assessment

See chapter 7.1 8.5.7 Period of availability of the analyser.

Criterion satisfied? yes

6.6 Detailed presentation of test results

Not applicable in this instance.

6.1 7.5.8 Converter efficiency

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

6.2 Equipment

Test specimens, ozone generator, NO test gas

6.3 Testing

VDI 4202-1:2018 additionally requires the converter efficiency to be tested at the end of the field test. The procedure was analogous to the testing of the conversion efficiency in the laboratory according to EN 14211 (2012).

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 50% and 95% of the maximum of the certification range of NO_2.

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

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

The converter efficiency is calculated as follows:

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

Where:

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

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

The 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 N200 measuring systems. The lowest value of the two NO_2 concentration is reported below.

	requirement	device 1		device 2	
converter efficiency E_c [%]	≥ 95%	98.6	✓	97.8	✓

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 8 presents the individual values.

Table 8: Individual data from the converter efficiency test at the end of the field test

				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]
	09:02:00	start					
O_3=0, NO=50%	09:14:00	0.0	0.3	486.9	487.2	488.6	488.9
	09:18:00	0.0	0.1	486.7	486.8	488.5	488.7
	09:22:00	0.0	0.3	486.9	487.2	488.8	489.2
	09:26:00	0.0	0.2	487.2	487.4	488.8	489.7
average		0.0	0.2	486.9	487.2	488.7	489.1
NO_2= 50% 130.75	09:50:00	135.0	138.9	346.1	485.2	348.6	487.4
	09:54:00	135.0	138.7	346.7	485.6	348.1	487.1
	09:58:00	135.0	139.4	346.6	485.9	348.0	487.2
	10:02:00	135.0	139.5	346.7	485.9	347.4	487.2
average		135.0	139.1	346.5	485.7	348.0	487.2
O_3=0, NO=50%	10:32:00	0.0	0.1	488.3	488.9	489.6	489.6
	10:36:00	0.0	0.2	488.7	488.5	489.7	489.9
	10:40:00	0.0	0.2	488.7	488.6	489.9	490.2
	10:44:00	0.0	0.2	488.9	488.9	490.2	490.3
average		0.0	0.2	488.7	488.7	489.9	490.0
NO_2= 95% 248.43	11:02:00	250.0	252.3	233.1	485.3	232.8	484.5
	11:06:00	250.0	252.1	233.5	485.2	232.9	484.2
	11:10:00	250.0	252.0	233.1	484.7	233.0	484.2
	11:14:00	250.0	252.6	233.2	485.3	232.7	484.2
average		250.0	252.3	233.2	485.1	232.9	484.3
O_3=0, NO=50%	11:30:00	0.0	-0.2	482.2	482.8	482.8	482.8

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 in 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 in 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

The 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

The 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

The 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)

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 11. 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 11 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) are calculated.

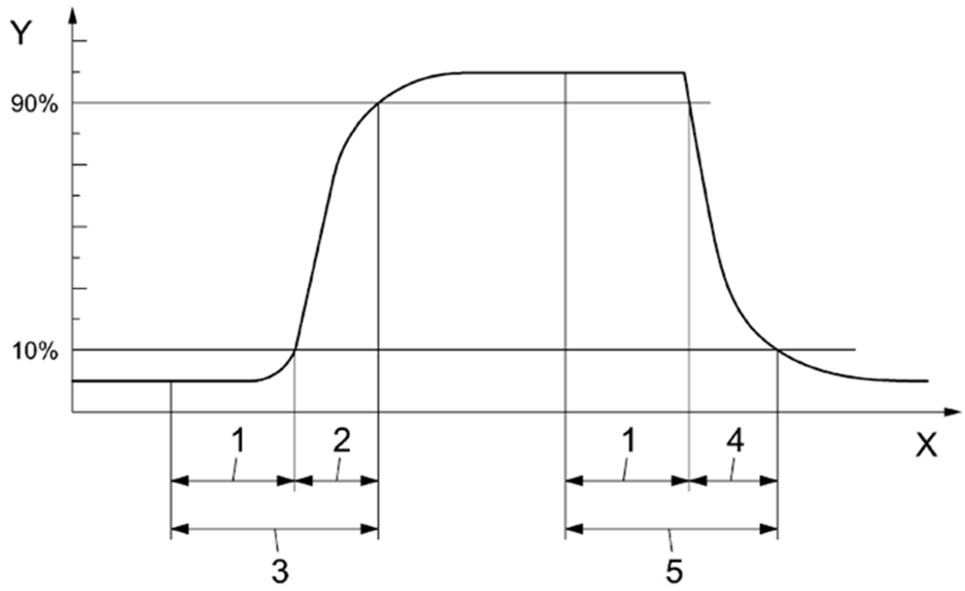
The test shall then be repeated with NO_2 at levels from less than 20 % to about 80 % of the maximum of the certification range of NO_2 and vice versa.

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

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

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

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



Key

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

Figure 11: Diagram illustrating the response time

7.3 Testing

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

7.4 Evaluation

Table 9: Response times of the two N200 measuring systems for NO

	requirement	device 1		device 2	
average rise t_r [s]	≤ 180 s	29	✓	30	✓
average fall t_f [s]	≤ 180 s	31	✓	30	✓
difference t_d [s]	≤ 10 s	-2,0	✓	0,0	✓

For system 1, the average t_r for NO was 29 sec, the average t_f was 31 sec and the average t_d was -2 sec.

For system 2, the average t_r for NO was 30 sec, the average t_f was 30 sec and the average t_d was 0 sec.

Table 10: Response times of the two N200 measuring systems for NO_2

	requirement	device 1		device 2	
average rise t_r [s]	≤ 180 s	34	✓	36	✓
average fall t_f [s]	≤ 180 s	34	✓	34	✓
difference t_d [s]	≤ 10 s	0,0	✓	2,0	✓

For unit 1, the average t_r for NO_2 was 34 sec, the average t_f was 34 sec and the average t_d was 0 sec.

For unit 2, the average t_r for NO_2 was 36 sec, the average t_f was 34 sec and the average t_d was 2 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 31 sec for NO and 34 sec for NO_2. For unit 2 it was 30 sec for NO and 36 sec for NO_2.

Criterion satisfied? yes

7.6 Detailed presentation of test results

Table 11: 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	08:50:00	08:50:30	08:51:00	08:56:00	08:56:32	08:57:00
	delta t		00:00:30			00:00:32	
	delta t [s]		30			32	
cycle 2	t = 0	09:02:00	09:02:28	09:03:00	09:08:00	09:08:29	09:09:00
	delta t		00:00:28			00:00:29	
	delta t [s]		28			29	
cycle 3	t = 0	09:14:00	09:14:30	09:15:00	09:20:00	09:20:31	09:21:00
	delta t		00:00:30			00:00:31	
	delta t [s]		30			31	
cycle 4	t = 0	09:26:00	09:26:28	09:27:00	09:32:00	09:32:32	09:33:00
	delta t		00:00:28			00:00:32	
	delta t [s]		28			32	

		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	08:50:00	08:50:32	08:51:00	08:56:00	08:56:30	08:57:00
	delta t		00:00:32			00:00:30	
	delta t [s]		32			30	
cycle 2	t = 0	09:02:00	09:02:30	09:03:00	09:08:00	09:08:32	09:09:00
	delta t		00:00:30			00:00:32	
	delta t [s]		30			32	
cycle 3	t = 0	09:14:00	09:14:28	09:15:00	09:20:00	09:20:27	09:21:00
	delta t		00:00:28			00:00:27	
	delta t [s]		28			27	
cycle 4	t = 0	09:26:00	09:26:30	09:27:00	09:32:00	09:32:31	09:33:00
	delta t		00:00:30			00:00:31	
	delta t [s]		30			31	

Table 12: Individual results of the response time for NO_2

		device 1					
	80%		rise			fall	
measuring range	209,21	0,0 0,00	0,9 188,28	1,0 209,21	1,0 209,21	0,1 20,92	0,0 0,00
cycle 1	t = 0	13:35:00	13:35:33	13:36:00	13:41:00	13:41:35	13:42:00
	delta t		00:00:33			00:00:35	
	delta t [s]		33			35	
cycle 2	t = 0	13:47:00	13:47:33	13:48:00	13:53:00	13:53:36	13:54:00
	delta t		00:00:33			00:00:36	
	delta t [s]		33			36	
cycle 3	t = 0	13:59:00	13:59:35	14:00:00	14:05:00	14:05:32	14:06:00
	delta t		00:00:35			00:00:32	
	delta t [s]		35			32	
cycle 4	t = 0	14:11:00	14:11:35	14:12:00	14:17:00	14:17:33	14:18:00
	delta t		00:00:35			00:00:33	
	delta t [s]		35			33	

		device 2					
	80%		rise			fall	
measuring range	209,21	0,0 0,00	0,9 188,28	1,0 209,21	1,0 209,21	0,1 20,92	0,0 0,00
cycle 1	t = 0	13:35:00	13:35:35	13:36:00	13:41:00	13:41:32	13:42:00
	delta t		00:00:35			00:00:32	
	delta t [s]		35			32	
cycle 2	t = 0	13:47:00	13:47:38	13:48:00	13:53:00	13:53:36	13:54:00
	delta t		00:00:38			00:00:36	
	delta t [s]		38			36	
cycle 3	t = 0	13:59:00	13:59:35	14:00:00	14:05:00	14:05:34	14:06:00
	delta t		00:00:35			00:00:34	
	delta t [s]		35			34	
cycle 4	t = 0	14:11:00	14:11:36	14:12:00	14:17:00	14:17:34	14:18:00
	delta t		00:00:36			00:00:34	
	delta t [s]		36			34	

7.1 8.4.4 Short-term drift

Short-term drift at zero shall not exceed 2.0 nmol/mol/12 h.

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

7.2 Testing

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

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

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

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

Where:

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

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

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

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

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

Where:

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

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

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

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

7.3 Testing

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

7.4 Evaluation

Table 13 indicates the measured value determined for the short-term drift.

Table 13: Results for the short-term drift

	requirements	device 1		device 2	
averange at zero at the beginning [nmol/mol]	-	-0.48		0.00	
averange at zero at the end (12h) [nmol/mol]	-	0.03		-0.12	
averange at span at the beginning [nmol/mol]	-	727.87		725.29	
averange at span at the end (12h) [nmol/mol]	-	727.51		726.31	
12-hour drift at zero $D_{s,z}$ [nmol/mol]	≤ 2,0	0.51	✓	-0.12	✓
12-hour drift at span $D_{s,s}$ [nmol/mol]	≤ 6,0	-0.87	✓	1.14	✓

7.5 Assessment

For NO, the value for the short-term drift at zero point was 0.51 nmol/mol for instrument 1; for instrument 2, it was -0.12 nmol/mol.

For NO, the value for the short-term drift at span point was -0.87 nmol/mol for instrument 1; for instrument 2, it was 1.14 nmol/mol.

Criterion satisfied? yes

7.6 Detailed presentation of test results

The individual values of the test are shown in Table 14 and Table 15.

Table 14: Individual results for short-term drift 1st test gas

at beginning		
zero level		
23.03.2022	device 1	device 2
time	[nmol/mol]	[nmol/mol]
16:25:00	-0.6	0.0
16:26:00	0.0	0.0
16:27:00	-0.6	0.0
16:28:00	-0.6	0.0
16:29:00	-0.6	0.0
16:30:00	-0.6	0.0
16:31:00	0.0	0.0
16:32:00	-0.6	0.0
16:33:00	-0.6	0.0
16:34:00	0.0	0.0
16:35:00	-0.6	0.0
16:36:00	-0.6	0.0
16:37:00	-0.6	0.0
16:38:00	-0.6	0.0
16:39:00	0.0	0.0
16:40:00	-0.6	0.0
16:41:00	-0.6	0.0
16:42:00	-0.6	0.0
16:43:00	-0.6	0.0
16:44:00	-0.6	0.0
average	**-0.5**	**0.0**

at beginning		
span level		
23.03.2022	device 1	device 2
time	[nmol/mol]	[nmol/mol]
16:50:00	726.3	722.7
16:51:00	726.3	723.3
16:52:00	726.9	723.9
16:53:00	726.9	724.5
16:54:00	728.1	725.1
16:55:00	728.1	725.1
16:56:00	728.1	725.7
16:57:00	728.1	725.7
16:58:00	727.5	725.7
16:59:00	728.1	726.3
17:00:00	728.1	726.3
17:01:00	728.1	726.3
17:02:00	728.1	725.7
17:03:00	727.5	725.7
17:04:00	728.1	725.7
17:05:00	728.7	725.7
17:06:00	728.7	725.7
17:07:00	728.7	725.7
17:08:00	728.1	725.7
17:09:00	728.7	725.1
average	**727.9**	**725.3**

Table 15: Individual results for short-term drift 2nd test gas

after 12h		
zero level		
24.03.2022	device 1	device 2
time	[nmol/mol]	[nmol/mol]
04:25:00	0.0	0.0
04:26:00	0.0	0.0
04:27:00	0.0	0.0
04:28:00	0.0	0.0
04:29:00	0.0	0.0
04:30:00	0.6	0.0
04:31:00	0.0	0.0
04:32:00	0.0	0.0
04:33:00	0.0	0.0
04:34:00	0.0	0.0
04:35:00	0.0	0.0
04:36:00	0.0	0.0
04:37:00	0.0	0.0
04:38:00	0.0	-0.6
04:39:00	0.0	-0.6
04:40:00	0.0	-0.6
04:41:00	0.0	-0.6
04:42:00	0.0	0.0
04:43:00	0.0	0.0
04:44:00	0.0	0.0
average	**0.0**	**-0.1**

after 12h		
span level		
24.03.2022	device 1	device 2
time	[nmol/mol]	[nmol/mol]
04:50:00	726.9	724.5
04:51:00	726.9	724.5
04:52:00	726.9	725.1
04:53:00	727.5	726.3
04:54:00	727.5	726.3
04:55:00	727.5	726.3
04:56:00	727.5	726.3
04:57:00	727.5	726.3
04:58:00	727.5	726.3
04:59:00	727.5	726.3
05:00:00	727.5	726.3
05:01:00	727.5	726.3
05:02:00	727.5	726.9
05:03:00	727.5	726.9
05:04:00	727.5	726.9
05:05:00	727.5	726.9
05:06:00	727.5	726.9
05:07:00	728.1	726.9
05:08:00	728.1	726.9
05:09:00	728.1	726.9
average	**727.5**	**726.3**

7.1 8.4.5 Repeatability standard deviation

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

7.2 Test procedure

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

From these measurements, the repeatability standard deviation (s_r) 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 of the measuring system is calculated from the repeatability standard deviation and the slope of the calibration function determined in accordance with chapter 8.4.6 according to the following equation:

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

Where:

l_{det} is the detection limit 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 previously. 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.

7.4 Evaluation

Table 16 presents the results for the repeatability standard deviation.

Table 16: 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	0.28	✓	0.25	✓
repeatability standard deviation $s_{r,ct}$ at c_t [nmol/mol]	≤ 3,0	0.56	✓	0.35	✓
detection limit [nmol/mol]		0.93		0.81	

7.5 Assessment

For NO, the value for the repeatability standard deviation at zero point was 0.28 nmol/mol for instrument 1; for instrument 2 it was 0.25 nmol/mol. Repeatability standard deviation at reference point was 0.56 nmol/mol for instrument 1 and 0.35 nmol/mol for instrument 2.

Criterion satisfied? yes

7.6 Detailed presentation of test results

Table 17 lists the results of individual measurements.

Table 17: Individual results for repeatability standard deviation

zero level		
	device 1	device 2
time	[nmol/mol]	[nmol/mol]
12:29:00	0.0	0.0
12:30:00	0.0	0.0
12:31:00	-0.6	0.0
12:32:00	-0.6	0.0
12:33:00	-0.6	0.0
12:34:00	-0.6	0.0
12:35:00	-0.6	0.0
12:36:00	-0.6	0.0
12:37:00	0.0	0.0
12:38:00	0.0	0.0
12:39:00	0.0	0.0
12:40:00	0.0	0.0
12:41:00	0.0	0.0
12:42:00	0.0	0.0
12:43:00	0.0	0.0
12:44:00	0.0	0.0
12:45:00	0.0	0.6
12:46:00	0.0	0.6
12:47:00	0.0	0.6
12:48:00	0.0	0.6
average	-0.2	0.1

c_t level		
	device 1	device 2
time	[nmol/mol]	[nmol/mol]
12:54:00	499.0	493.6
12:55:00	498.4	494.2
12:56:00	497.8	494.2
12:57:00	497.8	494.2
12:58:00	497.8	494.2
12:59:00	497.8	494.2
13:00:00	497.8	494.2
13:01:00	497.8	494.2
13:02:00	497.8	494.2
13:03:00	497.8	494.2
13:04:00	497.8	494.2
13:05:00	497.2	494.8
13:06:00	497.2	494.8
13:07:00	497.2	494.8
13:08:00	497.8	494.8
13:09:00	498.4	494.8
13:10:00	498.4	494.8
13:11:00	498.4	494.8
13:12:00	499.0	494.2
13:13:00	499.0	494.8
average	498.0	494.4

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 $(= \sum x_i / n)$
X_i is the individual x-value

The function $Y_i = a + B (X_i - X_z)$ is converted via the calculation of A into $Y_i = A + B * X_i$

$A = a – B * X_z$

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 component NO in accordance with the previously mentioned test specifications of EN 14211.

7.4 Evaluation

The following linear regressions were established:

Figure 12 and Figure 13 summarise the results of the group averages for NO.

Table 18: Analytical function variations

	requirements	device 1		device 2	
largest value of the relative residuals r_{max} [%]	≤ 4,0	0.40	✓	1.07	✓
residual at zero r_z [nmol/mol]	≤ 5,0	-0.24	✓	0.48	✓

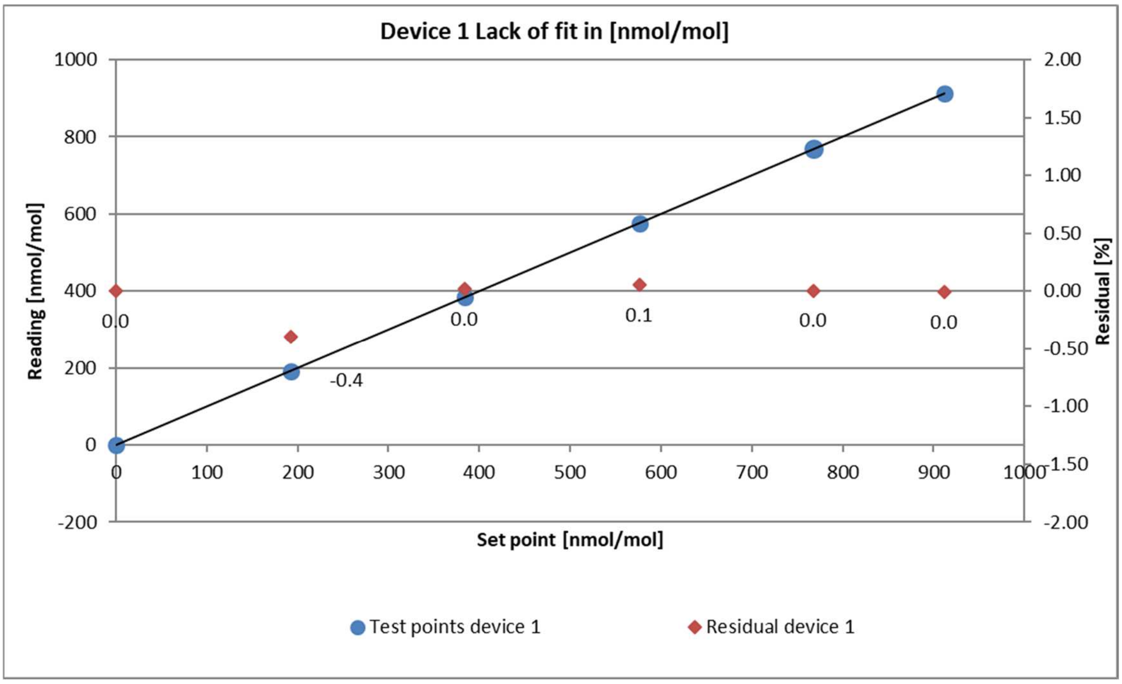


Figure 12: Analytical function obtained from the group averages for system 1

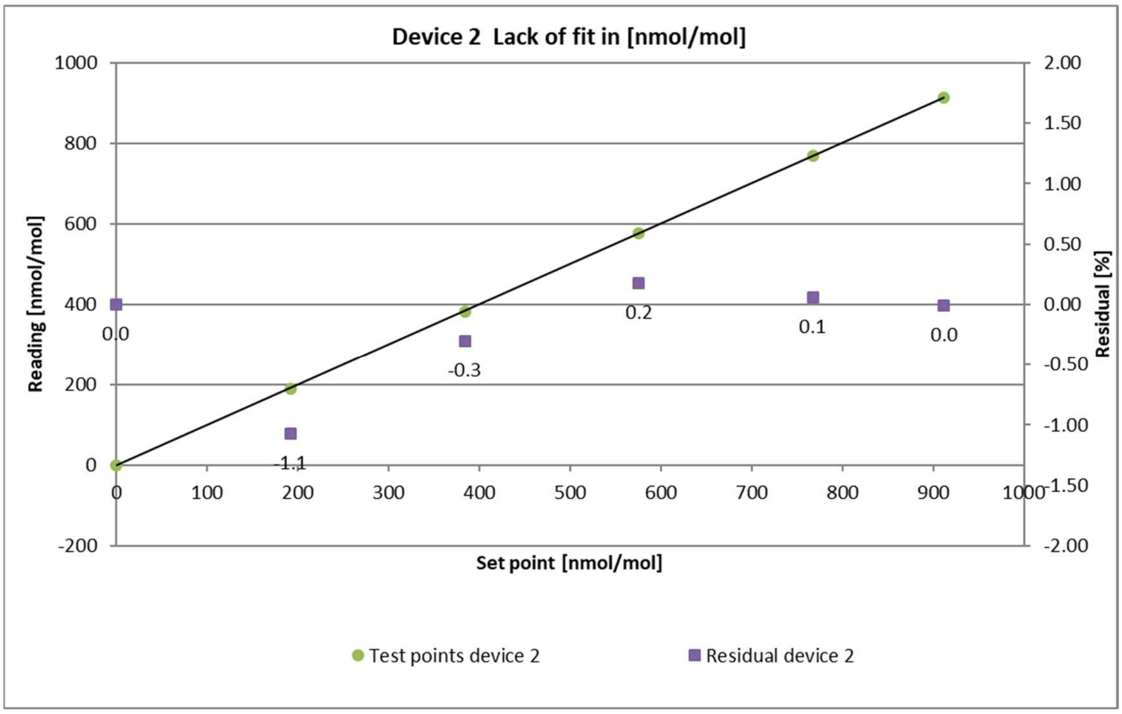


Figure 13: Analytical function obtained from the group averages for system 2

7.5 Assessment

The deviation from the linear regression line for instrument 1 is -0.24 nmol/mol at zero point and no more than 0.40% of the nominal value for concentrations above zero. The deviation from the linear regression line for instrument 2 was 0.48 nmol/mol at zero point and no more than 1.07% of the nominal value for concentrations above zero.

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

Criterion satisfied? yes

7.6 Detailed presentation of test results

Table 19 presents the individual test results.

Table 19: Individual results of the lack-of-fit test

		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
09:54:00	80	768.4	768.0	768.4	768.0
09:55:00	80	768.4	768.0	769.0	768.0
09:56:00	80	769.0	768.0	769.0	768.0
09:57:00	80	769.6	768.0	769.0	768.0
09:58:00	80	769.6	768.0	769.6	768.0
average		769.0		769.0	
$r_{c,rel}$		0.01		0.06	
10:04:00	40	384.2	384.0	382.4	384.0
10:05:00	40	384.2	384.0	382.4	384.0
10:06:00	40	384.2	384.0	382.4	384.0
10:07:00	40	384.2	384.0	382.4	384.0
10:08:00	40	384.2	384.0	382.4	384.0
average		384.2		382.4	
$r_{c,rel}$		0.02		-0.31	
10:14:00	0	-0.6	0.0	0.6	0.0
10:15:00	0	0.0	0.0	0.6	0.0
10:16:00	0	0.0	0.0	0.6	0.0
10:17:00	0	-0.6	0.0	0.6	0.0
10:18:00	0	0.0	0.0	0.0	0.0
average		-0.2		0.5	
r_z		-0.24		0.48	
10:24:00	60	576.6	576.0	577.2	576.0
10:25:00	60	576.6	576.0	577.2	576.0
10:26:00	60	576.6	576.0	577.2	576.0
10:27:00	60	577.2	576.0	577.2	576.0
10:28:00	60	577.2	576.0	576.6	576.0
average		576.8		577.1	
$r_{c,rel}$		0.05		0.18	
10:34:00	20	191.2	192.0	188.8	192.0
10:35:00	20	191.2	192.0	188.8	192.0
10:36:00	20	191.2	192.0	188.8	192.0
10:37:00	20	190.6	192.0	189.4	192.0
10:38:00	20	190.6	192.0	189.4	192.0
average		191.0		189.0	
$r_{c,rel}$		-0.40		-1.07	
10:44:00	95	913.3	912.0	913.3	912.0
10:45:00	95	912.7	912.0	912.7	912.0
10:46:00	95	913.3	912.0	912.7	912.0
10:47:00	95	913.3	912.0	912.7	912.0
10:48:00	95	913.3	912.0	912.7	912.0
average		913.2		912.8	
$r_{c,rel}$		-0.01		-0.01	

7.1 8.4.7 Sensitivity coefficient of sample gas pressure

The sensitivity coefficient of 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.

7.3 Testing

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

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 of sample gas pressure were determined.

Table 20: Sensitivity coefficient of the sample gas pressure

	requirement	device 1		device 2	
sensitivity coeff. sample gas pressure b_{gp} [nmol/mol/kPa]	≤ 8,0	0.82	✓	0.86	✓

7.5 Assessment

For NO, the sensitivity coefficient of sample gas pressure was 0.82 nmol/mol/kPa for instrument 1; for instrument 2 it was 0.86 nmol/mol/kPa.

Criterion satisfied? yes

7.6 Detailed presentation of test results

Table 21: Individual results of the sensitivity of the sample gas pressure for NO

time	pressure [kPa]	concentration	device 1 [nmol/mol]	device 2 [nmol/mol]
12:16:00	80	720.0	737.7	738.9
12:17:00	80	720.0	737.7	738.9
12:18:00	80	720.0	737.1	738.9
average C_{P1}			737.5	738.9
12:26:00	110	720.0	712.5	713.1
12:27:00	110	720.0	713.1	713.1
12:28:00	110	720.0	713.1	713.7
average C_{P2}			712.9	713.3

7.1 8.4.8 Sensitivity coefficient of sample gas temperature

The sensitivity coefficient of sample gas temperature shall be ≤ 3.0 nmol/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 of 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 of 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.

7.3 Testing

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

For the test, the test gas and the dilution gas were placed in the climatic chamber. The test gas mixture was fed through an approx. 50 metre long hose bundle, which was located in a climate 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 0 °C and 30 °C respectively.

7.4 Evaluation

Table 22: Sensitivity coefficient of the sample gas temperature

	requirement	device 1		device 2	
sensitivity coeff. sample gas temperature b_{gt} [nmol/mol/K]	≤ 3,0	0.05	✓	0.09	✓

7.5 Assessment

The sensitivity coefficient of the sample gas temperature was 0.05 nmol/mol/K for instrument 1 and 0.09 nmol/mol/K for instrument 2.

Criterion satisfied? yes

7.6 Detailed presentation of test results

Table 23: Individual results of the influence of the sample gas temperature

			device 1	device 2
time	temp [ºC]	concentration	[nmol/mol]	[nmol/mol]
08:23:00	0	720.00	722.70	721.50
08:24:00	0	720.00	723.30	721.50
08:25:00	0	720.00	723.91	721.50
average $C_{GT,1}$			723.30	721.50
12:21:00	30	720.00	721.50	719.10
12:22:00	30	720.00	721.50	718.49
12:23:00	30	720.00	722.10	718.49
average $C_{GT,2}$			721.70	718.69

7.1 8.4.9 Sensitivity coefficient of surrounding temperature

The sensitivity coefficient of surrounding temperature shall be ≤ 3.0 nmol/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_I = 20 °C;

3) at the maximum temperature T_{max} = 30 °C (here 45 °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_I, T_{min}, T_I and T_I, T_{max}, T_I

At the first temperature (T_I), 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_I, at T_{min} and again at T_I. This measurement procedure shall be repeated at the temperature sequence of T_I, T_{max} and at T_I.

In order to exclude any possible drift due to factors other than temperature, the measurements at T_I 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 previously.

According to the manufacturer's specification, the measuring system can be used in a temperature range from 0 °C to 45 °C. Therefore, the upper temperature limit was set to 45 °C during the test of sensitivities to ambient temperature.

7.4 Evaluation

The following sensitivity coefficients of surrounding temperature have been determined:

Table 24: Sensitivity coefficient of surrounding temperature

	requirements	device 1		device 2	
sensitivity coefficient at 0 ºC for zero level [nmol/mol/K]	≤ 3,0	0.010	✓	0.010	✓
sensitivity coefficient at 45 ºC for zero level [nmol/mol/K]	≤ 3,0	0.016	✓	0.000	✓
sensitivity coefficient at 0 ºC for span level [nmol/mol/K]	≤ 3,0	0.110	✓	0.210	✓
sensitivity coefficient at 45 ºC for span level [nmol/mol/K]	≤ 3,0	0.581	✓	0.269	✓

As is evident from Table 24, the sensitivity coefficient of the surrounding temperature at zero and at span point meets the performance criteria.

7.5 Assessment

The sensitivity coefficient of the surrounding temperature b_{st} did not exceed the performance criterion specified at 3.0 nmol/mol/K. For the purpose of the uncertainty calculation, the largest value b_{st} is used for both instruments. For NO, this was 0.581 nmol/mol/K for instrument 1 and 0.269 nmol/mol/K for instrument 2.

Criterion satisfied? yes

7.6 Detailed presentation of test results

Table 25 presents the individual test results.

Table 25: Individual results of the sensitivity coefficient of surrounding temperature

	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]
03.05.2022	07:12:00	20	0.0	0.0	07:21:00	20	719.7	720.3
03.05.2022	07:13:00	20	0.0	0.0	07:22:00	20	719.7	720.3
03.05.2022	07:14:00	20	0.0	0.0	07:23:00	20	719.1	720.9
average ($X_{1(TS1)}$)			0.0	0.0			719.5	720.5
03.05.2022	16:27:00	0	0.0	-0.6	16:38:00	0	723.9	720.9
03.05.2022	16:28:00	0	0.0	0.0	16:39:00	0	723.3	719.7
03.05.2022	16:29:00	0	0.0	0.0	16:40:00	0	722.7	719.7
average($X_{Ts,1}$)		0	0.0	-0.2			723.3	720.1
04.05.2022	07:05:00	20	-0.6	0.0	07:12:00	20	722.7	728.7
04.05.2022	07:06:00	20	-0.6	0.0	07:13:00	20	722.7	728.1
04.05.2022	07:07:00	20	0.0	0.0	07:14:00	20	722.7	727.5
average ($X_{2(TS1)}$) = ($X_{1(TS2)}$)			-0.4	0.0			722.7	728.1
04.05.2022	15:37:00	45	0.6	0.0	15:45:00	45	735.9	717.9
04.05.2022	15:38:00	45	0.0	0.0	15:46:00	45	736.5	718.5
04.05.2022	15:39:00	45	0.0	0.0	15:47:00	45	737.1	718.5
average($X_{Ts,2}$)			0.2	0.0			736.5	718.3
05.05.2022	16:08:00	20	0.0	0.0	16:16:00	20	720.9	722.1
05.05.2022	16:09:00	20	0.0	0.0	16:17:00	20	721.5	722.1
05.05.2022	16:10:00	20	0.0	0.0	16:18:00	20	721.5	721.5
average ($X_{2(TS2)}$)			0.0	0.0			721.3	721.9

7.1 8.4.10 Sensitivity coefficient of electrical voltage

The sensitivity coefficient of 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 of 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 of electrical voltage, a transformer was looped into the measuring system’s voltage supply. Test gases were applied to the zero and span point at various voltages.

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

7.4 Evaluation

The following sensitivity coefficients of electrical voltage have been determined:

Table 26: Sensitivity coefficient of electrical voltage

	requirement	device 1		device 2	
sensitivity coeff. of voltage b_v at zero level [nmol/mol/V]	≤ 0,3	0.00	✓	0.00	✓
sensitivity coeff. of voltage b_v at span level [nmol/mol/V]	≤ 0,3	0.00	✓	0.01	✓

7.5 Assessment

At no test item did the sensitivity coefficient of electrical voltage b_v exceed the value of 0.30 nmol/mol/V specified in standard EN 14211. For the purpose of the uncertainty calculation, the largest b_v is used for both instruments. For NO, this is 0.00 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 27: Individual results of the sensitivity coefficient of electrical voltage for NO

			device 1	device 2
time	voltage [V]	concentration	[nmol/mol]	[nmol/mol]
12:48:00	207	0.0	0.0	0.0
12:49:00	207	0.0	0.0	0.0
12:50:00	207	0.0	0.0	0.0
average C_{V1} at zero			0.0	0.0
13:00:00	253	0.0	0.0	0.0
13:01:00	253	0.0	0.0	0.0
13:02:00	253	0.0	0.0	0.0
average C_{V2} at zero			0.0	0.0
13:17:00	207	720.0	720.9	720.9
13:18:00	207	720.0	720.9	720.9
13:19:00	207	720.0	721.5	720.9
average C_{V1} at Span			721.1	720.9
13:29:00	253	720.0	720.9	721.5
13:30:00	253	720.0	720.9	721.5
13:31:00	253	720.0	721.5	720.9
average C_{V2} at Span			721.1	721.3

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 shown in Table 28. The influence of each interferent shall be determined separately. The concentration of the measurand shall be corrected for the dilution flux due to the addition of the interfering component (e.g. water vapour).

After adjustment of the analyser at zero and span level, the analyser shall be fed with a mixture of zero gas and the interferent to be investigated with the concentration as given in Table 28. With this mixture, one independent measurement of NO followed by two individual measurements of NO shall be carried out. This procedure shall be repeated with a mixture of the measurand at concentration c_t and the interferent to be investigated. The influence quantities at zero and concentration c_t are calculated from:

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

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

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 previously. The instruments were set at zero and the concentration c_t (500 ppb). Zero and test gas with the various interfering components were then applied. The interferents listed in Table 28 were applied in the concentrations indicated. As required by standard EN 14211, the measured NO_x concentration shall be used instead of the NO concentration when testing the interferent NH_3.

Table 28: 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 29: Influence of the tested interferents for NO (c_t = 500±50 nmol/mol)

	requirements	**device 1**		**device 2**	
influence quantity interferent H_2O at zero [nmol/mol/V]	≤ 5.0 nmol/mol	1.2	✓	1.0	✓
influence quantity interferent H_2O at c_t [nmol/mol/V]	≤ 5.0 nmol/mol	-2.4	✓	-1.2	✓
influence quantity interferent CO_2 at zero [nmol/mol/V]	≤ 5.0 nmol/mol	-0.6	✓	-0.6	✓
influence quantity interferent CO_2 at c_t [nmol/mol/V]	≤ 5.0 nmol/mol	1.6	✓	0.4	✓
influence quantity interferent NH_3 at zero [nmol/mol/V]	≤ 5.0 nmol/mol	0.0	✓	0.0	✓
influence quantity interferent NH3 at c_t [nmol/mol/V]	≤ 5.0 nmol/mol	1.6	✓	2.0	✓

7.5 Assessment

At zero point the results for the interference were 1.20 nmol/mol (AMS 1) and 1.00 nmol/mol (AMS 2) for H_2O, -0.60 nmol/mol (AMS 1) and -0.60 nmol/mol (AMS 2) for CO_2, and finally 0.00 nmol/mol (AMS 1) and 0.00 nmol/mol (AMS 2) for NH_3.

For the cross-sensitivity at the limit value ct, the values were -2.40 nmol/mol for instrument 1 and -1.20 nmol/mol for instrument 2 for H_2O, 1.60 nmol/mol for instrument 1 and 0.40 nmol/mol for instrument 2 for CO_2, and 1.60 nmol/mol for instrument 1 and 2.00 nmol/mol for NH_3.

Criterion satisfied? yes

7.6 Detailed presentation of test results

Table 30 presents the individual test results.

Table 30: Individual values from the interfering substances test

	without interferents			with interferents		
	time	device 1	device 2	time	device 1	device 2
zero gas + H_2O (19 mmol/mol)	11:05:00	0.0	0.0	11:20:00	1.2	1.2
	11:06:00	0.0	0.0	11:21:00	1.2	1.2
	11:07:00	0.0	0.6	11:22:00	1.2	1.2
	average x_z	0.0	0.2	average x_z	1.2	1.2
test gas c_t + H_2O (19 mmol/mol)	12:04:00	501.4	500.8	12:23:00	499.6	499.6
	12:05:00	501.4	500.2	12:24:00	499.0	499.0
	12:06:00	501.4	500.2	12:25:00	498.4	499.0
	average x_{ct}	501.4	500.4	average x_{ct}	499.0	499.2
zero gas + CO_2 (500 µmol/mol)	10:22:00	0.6	0.6	10:37:00	0.0	0.0
	10:23:00	0.6	0.6	10:38:00	0.0	0.0
	10:24:00	0.6	0.6	10:39:00	0.0	0.0
	average x_z	0.6	0.6	average x_z	0.0	0.0
test gas c_t + CO_2 (500 µmol/mol)	09:52:00	505.1	504.5	10:07:00	506.9	505.1
	09:53:00	505.1	504.5	10:08:00	506.9	505.1
	09:54:00	505.7	504.5	10:09:00	506.9	504.5
	average x_{ct}	505.3	504.5	average x_{ct}	506.9	504.9
zero gas + NH_3 (200 nmol/mol)	10:43:00	0.0	0.0	10:53:00	0.0	0.0
	10:44:00	0.0	0.0	10:54:00	0.0	0.0
	10:45:00	0.0	0.0	10:55:00	0.0	0.0
	average x_z	0.0	0.0	average x_z	0.0	0.0
test gas c_t + NH_3 (200 nmol/mol)	11:44:00	498.4	498.4	11:54:00	499.6	499.6
	11:45:00	498.4	497.2	11:55:00	500.2	499.6
	11:46:00	498.4	497.2	11:56:00	500.2	499.6
	average x_{ct}	500.0	497.6	average x_{ct}	500.0	499.6

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 gas 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:

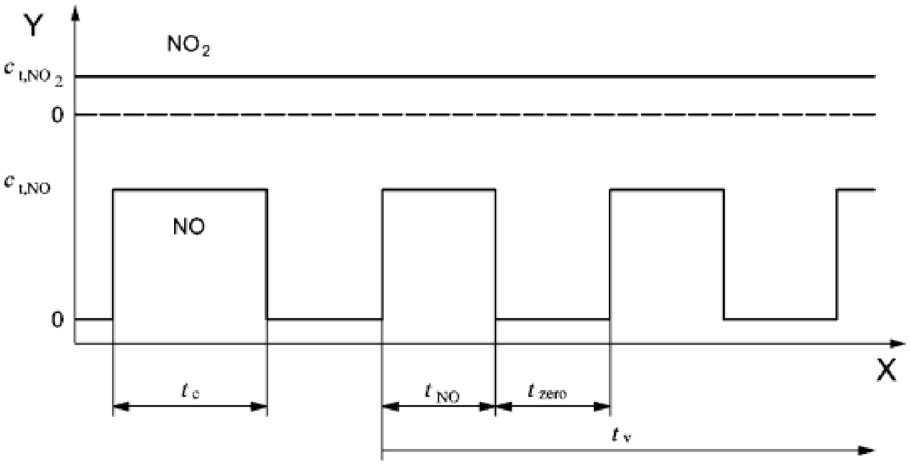
$$E_{av} = \frac{C_{const}^{av} - 2C_{var}^{av}}{C_{const}^{av}} * 100$$

Where:

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

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

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



Key

X time

Y concentration (nmol/mol)

Figure 14: 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 a step change of the NO concentration was applied 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.

7.4 Evaluation

The following averages were determined during the test:

Table 31: Results of the averaging test

	requirement	device 1		device 2	
averaging effect E_{av} [%]	≤ 7%	0.9	✓	-0.3	✓

This results in the following averaging effects:

System 1: 0.9%

System 2: -0.3%

7.5 Assessment

The performance criterion of EN 14211 for the averaging test was fully complied with at 0.9 % and -0.3 % respectively.

Criterion satisfied? yes

7.6 Detailed presentation of test results

Table 32 presents the individual results of the averaging test.

Table 32: Results of the averaging test

		device 1	device 2
	time	[nmol/mol]	[nmol/mol]
average constant concentration $C_{av,c}$	09:06:00	614.2	613.4
	till		
	09:25:00		
average variable concentration $C_{av,c}$	09:26:00	299.5	309.9
	till		
	09:45:00		

		device 1	device 2
	time	[nmol/mol]	[nmol/mol]
average constant concentration $C_{av,c}$	09:58:00	603.8	603.3
	till		
	10:17:00		
average variable concentration $C_{av,c}$	10:18:00	300.2	306.6
	till		
	10:37:00		

		device 1	device 2
	time	[nmol/mol]	[nmol/mol]
average constant concentration $C_{av,c}$	10:47:00	602.7	601.9
	till		
	11:06:00		
average variable concentration $C_{av,c}$	11:07:00	302.0	295.8
	till		
	10:26:00		

7.1 8.4.13 Difference sample/calibration port

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

7.2 Test procedures

If the analyser has different ports for feeding sample gas and calibration gas, the difference in response of the analyser to feeding through the sample or calibration port shall be tested. The test shall be carried out by feeding the analyser with a test gas with a concentration of 70% to 80% of the maximum of the certification range 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 33: Results of determining the difference between sample/calibration inlet

	requirement	device 1		device 2	
difference sample/calibration port Δx_{cs} [%]	≤ 1%	-0.19	✓	-0.03	✓

7.5 Assessment

The performance criterion of EN 14211 was fully met with a maximum deviation of -0.19 % and -0.03 % respectively.

Criterion satisfied? yes

7.6 Detailed presentation of test results

Table 34 presents the individual results of the averaging test:

Table 34: Individual results for testing the difference between sample and calibration port

		device 1	device 2
	time	[nmol/mol]	[nmol/mol]
calibration port	11:58:00	720.3	720.3
	11:59:00	719.7	720.3
	12:00:00	720.3	720.9
sample port	12:09:00	721.5	720.3
	12:10:00	721.5	720.9
	12:11:00	721.5	720.9

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 50% and 95% of the maximum of the certification range of NO_2.

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

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

The converter efficiency is calculated as follows:

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

Where:

E_{conv} is the converter efficiency in %;

$(NO_x)_i$ is the average of the four individual measurements at the NO_x 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 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 N200 measuring systems. The lowest value of the two NO_2 concentration is reported below.

	requirement	device 1		device 2	
converter efficiency E_c [%]	≥ 98%	99.2	✓	99.3	✓

7.5 Assessment

The performance criterion of EN 14211 was fully met with a converter efficiency of at least 99.2 %.

Criterion satisfied? yes

7.6 Detailed presentation of test results

Table 35 presents the individual values.

Table 35: Individual results for the converter efficiency

				device 1		device 2	
	time	O_3 [nmol/mol]	NO_2 [nmol/mol]	NO [nmol/mol]	NO_x [nmol/mol]	NO [nmol/mol]	NO_x [nmol/mol]
	08:54:00	start					
O_3=0, NO=50%	09:06:00	0.0	-0.2	482.2	482.2	484.6	483.4
	09:10:00	0.0	-0.2	483.4	482.8	484.6	484.0
	09:14:00	0.0	-0.2	483.4	482.8	484.6	483.4
	09:18:00	0.0	0.0	483.4	482.8	484.6	483.4
average		0.0	-0.1	483.1	482.7	484.6	483.6
NO_2= 50% 130.75	09:42:00	134.0	136.7	345.1	481.6	346.3	482.2
	09:46:00	134.0	133.8	346.3	481.6	348.1	482.2
	09:50:00	134.0	134.4	345.7	482.2	348.1	482.8
	09:54:00	134.0	135.2	345.7	482.8	348.1	483.4
average		134.0	135.0	345.7	482.1	347.7	482.7
O_3=0, NO=50%	10:54:00	0.0	0.5	482.2	482.8	482.2	480.4
	10:58:00	0.0	0.2	482.8	481.6	483.4	482.2
	11:02:00	0.0	0.5	481.6	481.6	482.8	481.6
	11:06:00	0.0	0.3	482.2	482.8	482.8	482.2
average		0.0	0.4	482.2	482.2	482.8	481.6
NO_2= 95% 248.43	11:21:00	248.0	248.9	231.5	481.0	230.9	479.8
	11:25:00	248.0	249.3	232.1	479.8	230.9	480.4
	11:29:00	248.0	248.6	232.1	479.2	230.9	480.4
	11:33:00	248.0	248.4	232.1	481.0	230.9	479.8
average		248.0	248.8	231.9	480.3	230.9	480.1
O_3=0, NO=50%	11:45:00	0.0	-0.2	482.2	482.8	482.8	482.8

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 N200 measuring system is approximately 12.0 ml from the sample inlet to the measuring cell. The sample gas flow is at 0.5 l/min. This results in a residence time in the analyser of 1.5 s.

7.4 Evaluation

Not applicable.

7.5 Assessment

Residence time in the analyser was ca. 1.5 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;

$C_{S,0}$ 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 36 and Table 37 report the measured values for bi-weekly test gas applications. Pursuant to EN 14211, the test shall be performed at a concentration level of 70% to 80% of the certification range for NO.

7.4 Evaluation

Table 36: Long-term drift at zero for NO

		requierment	Device 1		Device 2	
average start $C_{z,1}$ at zero [nmol/mol]	16.05.2022	≤ 5,0	--	✓	--	✓
long term drift $D_{L,Z}$ at zero [nmol/mol]	30.05.2022	≤ 5,0	0.00	✓	0.00	✓
long term drift $D_{L,Z}$ at zero [nmol/mol]	13.06.2022	≤ 5,0	0.00	✓	0.00	✓
long term drift $D_{L,Z}$ at zero [nmol/mol]	27.06.2022	≤ 5,0	0.00	✓	0.00	✓
long term drift $D_{L,Z}$ at zero [nmol/mol]	11.07.2022	≤ 5,0	0.00	✓	0.00	✓
long term drift $D_{L,Z}$ at zero [nmol/mol]	25.07.2022	≤ 5,0	0.00	✓	0.12	✓
long term drift $D_{L,Z}$ at zero [nmol/mol]	08.08.2022	≤ 5,0	0.84	✓	0.96	✓
long term drift $D_{L,Z}$ at zero [nmol/mol]	22.08.2022	≤ 5,0	0.00	✓	0.00	✓

Table 37: Long-term drift at span for NO

		requierment	Device 2 1		Device 2	
average start $C_{s,1}$ at span [nmol/mol]	16.05.2022	≤ 5 %	--	✓	--	✓
long term drift $D_{L,S}$ at span [nmol/mol]	30.05.2022	≤ 5 %	0.12	✓	-0.23	✓
long term drift $D_{L,S}$ at span [nmol/mol]	13.06.2022	≤ 5 %	-0.08	✓	-0.58	✓
long term drift $D_{L,S}$ at span [nmol/mol]	27.06.2022	≤ 5 %	-0.44	✓	-0.48	✓
long term drift $D_{L,S}$ at span [nmol/mol]	11.07.2022	≤ 5 %	-0.41	✓	-0.85	✓
long term drift $D_{L,S}$ at span [nmol/mol]	25.07.2022	≤ 5 %	-0.65	✓	-1.00	✓
long term drift $D_{L,S}$ at span [nmol/mol]	08.08.2022	≤ 5 %	-1.19	✓	-1.27	✓
long term drift $D_{L,S}$ at span [nmol/mol]	22.08.2022	≤ 5 %	-0.90	✓	-0.70	✓

7.5 Assessment

Maximum long-term drift at zero point $D_{l,z}$ for NO was at 0.84 nmol/mol for instrument 1 and 0.96 nmol/mol for instrument 2. Maximum long-term drift at span point $D_{l,s}$ for NO was at -1.19% for instrument 1 and -1.27% for instrument 2.

Criterion satisfied? yes

7.6 Detailed presentation of test results

Table 38 presents the individual values obtained for the determination of the long-term drift.

Table 38: Results of the drift test for NO

Zero Concentration			
		Device 1	Device 2
Date	Time	[nmol/mol]	[nmol/mol]
16.05.2022	11:42:00	0.6	0.60
	11:43:00	0.60	0.60
	11:44:00	0.60	0.60
	Mittel	0.60	0.60
	11:46:00	0.6	0.60
	11:47:00	0.60	0.60
	11:48:00	0.60	0.60
	Mittel	0.60	0.60
	11:50:00	0.6	0.60
	11:51:00	0.60	0.60
	11:52:00	0.60	0.60
	Mittel	0.60	0.60
	11:54:00	0.6	0.60
	11:55:00	0.60	0.60
	11:56:00	0.60	0.60
	Mittel	0.60	0.60
	11:58:00	0.6	0.60
	11:59:00	0.60	0.60
	12:00:00	0.60	0.60
		0.60	0.60
Average field start $c_{z,0}$		**0.60**	**0.60**
30.05.2022	08:35:00	0.60	0.60
	08:36:00	0.60	0.60
	08:37:00	0.60	0.60
	08:38:00	0.60	0.60
	08:39:00	0.60	0.60
	aver. $c_{z,1}$	**0.60**	**0.60**
13.06.2022	07:25:00	0.60	0.60
	07:26:00	0.60	0.60
	07:27:00	0.60	0.60
	07:28:00	0.60	0.60
	07:29:00	0.60	0.60
	aver. $c_{z,1}$	**0.60**	**0.60**
27.06.2022	07:23:00	0.60	0.60
	07:24:00	0.60	0.60
	07:25:00	0.60	0.60
	07:26:00	0.60	0.60
	07:27:00	0.60	0.60
	aver. $c_{z,1}$	**0.60**	**0.60**
11.07.2022	07:48:00	0.60	0.60
	07:49:00	0.60	0.60
	07:50:00	0.60	0.60
	07:51:00	0.60	0.60
	07:52:00	0.60	0.60
	aver. $c_{z,1}$	**0.60**	**0.60**
25.07.2022	07:10:00	0.60	1.20
	07:11:00	0.60	0.60
	07:12:00	0.60	0.60
	07:13:00	0.60	0.60
	07:14:00	0.60	0.60
	aver. $c_{z,1}$	**0.60**	**0.72**
08.08.2022	07:19:00	1.80	1.80
	07:20:00	1.80	1.80
	07:21:00	1.20	1.80
	07:22:00	1.20	1.20
	07:23:00	1.20	1.20
	aver. $c_{z,1}$	**1.44**	**1.56**
22.08.2022	08:13:00	0.60	0.60
	08:14:00	0.60	0.60
	08:15:00	0.60	0.60
	08:16:00	0.60	0.60
	08:17:00	0.60	0.60
	aver. $c_{z,1}$	**0.60**	**0.60**

C_t-Concentration			
		Device 1	Device 2
Date	Time	[nmol/mol]	[nmol/mol]
16.05.2022	12:06:00	723.30	723.30
	12:07:00	723.30	723.30
	12:08:00	723.91	723.30
	Mittel	723.50	723.30
	12:10:00	723.91	723.30
	12:11:00	724.51	723.30
	12:12:00	724.51	723.30
	Mittel	724.31	723.30
	12:14:00	725.11	723.91
	12:15:00	725.11	723.91
	12:16:00	725.11	723.91
	Mittel	725.11	723.91
	12:18:00	724.51	723.30
	12:19:00	725.11	723.91
	12:20:00	725.11	723.91
	Mittel	724.91	723.70
	12:22:00	725.11	723.91
	12:23:00	725.11	723.91
	12:24:00	725.11	723.91
		725.11	723.91
Average field start $c_{s,0}$		**724.59**	**723.62**
30.05.2022	08:44:00	725.71	722.10
	08:45:00	725.71	722.10
	08:46:00	725.71	722.10
	08:47:00	725.11	722.10
	08:48:00	725.11	721.50
	aver. $c_{s,1}$	**725.47**	**721.98**
13.06.2022	07:33:00	722.70	718.49
	07:34:00	723.91	719.70
	07:35:00	724.51	719.70
	07:36:00	724.51	719.70
	07:37:00	724.51	719.70
	aver. $c_{s,1}$	**724.03**	**719.46**
27.06.2022	07:31:00	719.70	718.49
	07:32:00	721.50	720.30
	07:33:00	721.50	720.30
	07:34:00	722.10	720.90
	07:35:00	722.10	720.90
	aver. $c_{s,1}$	**721.38**	**720.18**
11.07.2022	07:58:00	720.90	717.29
	07:59:00	720.90	716.69
	08:00:00	721.50	717.29
	08:01:00	722.10	717.89
	08:02:00	722.70	718.49
	aver. $c_{s,1}$	**721.62**	**717.53**
25.07.2022	07:20:00	719.10	715.49
	07:21:00	719.70	715.49
	07:22:00	719.70	716.69
	07:23:00	720.30	717.29
	07:24:00	720.90	717.89
	aver. $c_{s,1}$	**719.94**	**716.57**
08.08.2022	07:27:00	716.69	713.68
	07:28:00	716.69	715.49
	07:29:00	716.69	715.49
	07:30:00	717.29	716.09
	07:31:00	717.29	716.69
	aver. $c_{s,1}$	**716.93**	**715.49**
22.08.2022	08:23:00	716.69	718.49
	08:24:00	717.29	718.49
	08:25:00	717.89	718.49
	08:26:00	719.10	718.49
	08:27:00	719.70	719.10
	aver. $c_{s,1}$	**718.13**	**718.61**

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 averages over the field test period according to the equation stated above.

7.4 Evaluation

Table 39: Reproducibility standard deviation for NO_2 based on all data from the field test

reproducibility standard deviation in field		
no. of measurments (1h- average)	[n]	2348
average of both analyzers (3 month)	[nmol/mol]	13.97
standard deviation from paired measurements	[nmol/mol]	0.499
reproducibility standard deviation in field $S_{r,f}$	**[%]**	**3.57**
requirement	≤ 5,0 %	✓

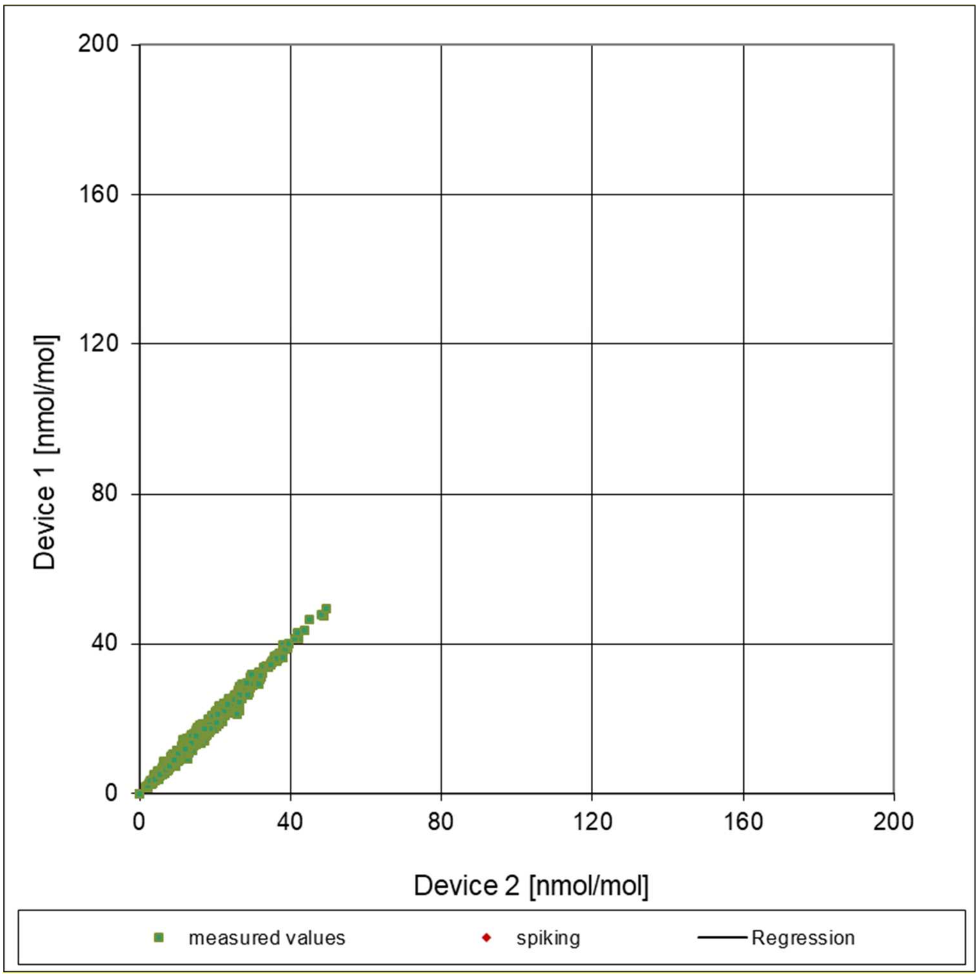


Figure 15: Reproducibility standard deviation for NO_2 under field conditions

The reproducibility standard deviation under field conditions was at 3.57% 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 % related to the mean value over the duration of the field test of 3 months. Thus, the requirements of EN 14211 are satisfied.

Criterion satisfied? yes

7.6 Detailed presentation of test results

As an overview, the results of the reproducibility standard deviation for NO are also shown here. According to EN 14211, the evaluation of the reproducibility standard deviation is carried out in the field with NO_2. As such, the following data are listed for information only.

Table 40: Reproducibility standard deviation for NO based on all data from the field test

reproducibility standard deviation in field		
no. of measurments (1h- average)	[n]	2348
average of both analyzers (3 month)	[nmol/mol]	10.86
standard deviation from paired measurements	[nmol/mol]	0.386
reproducibility standard deviation in field $S_{r,f}$	**[%]**	**3.55**
requirement	≤ 5,0 %	✓

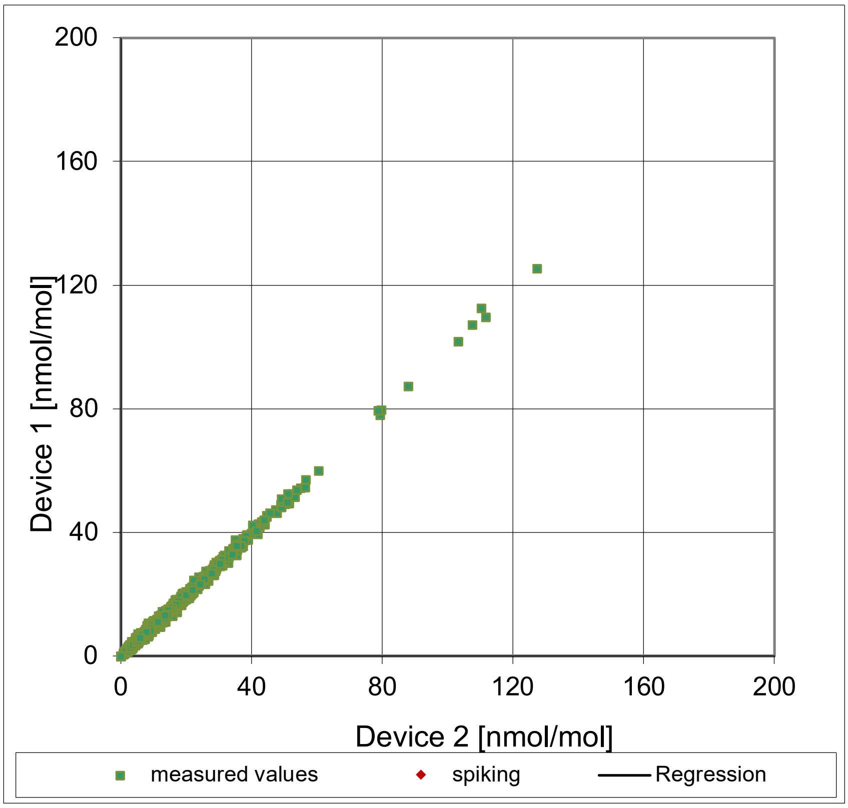


Figure 16: Reproducibility standard deviation for NO under field conditions

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. A check of the zero and span point must be carried out at least every 14 days in accordance with EN 14211.

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 that this check is performed 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 occurred during this period.

Evaluation

Outage times which occurred during the field test are listed in Table 41.

Table 41: Availability of the N200 measuring system

		System 1	System 2
Operation time	h	2348	2348
Outage time	h	0	0
Maintenance time	h	8	8
Actual operating time	h	2340	2340
Actual operating time incl. maintenance times	h	2348	2348
Availability	%	100	100

The maintenance times result from the daily test gas applications to determine the drift behaviour and the maintenance interval, as well as the times required to replace the device-internal particle filters in the sample gas path.

7.5 Assessment

The availability was 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 42 summarises the results for items 1 and 3.

Table 43 and Table 45 contain the results regarding item 2.

Table 44 and Table 46 contain the results regarding item 4.

Table 42: 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: 0.28 nmol/mol (NO) S_r System 2: 0.25 nmol/mol (NO)	yes	88
8.4.5 Repeatability standard deviation at concentration level c_t	≤ 3.0 nmol/mol	S_r System 1: 0.56 nmol/mol (NO) S_r System 2: 0.35 nmol/mol (NO)	yes	88
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 -0.24 nmol/mol (NO) X_l System 1: RP 0.40% (NO) $X_{l,z}$ System 2: ZP 0.48 nmol/mol (NO) X_l System 2: RP 1.07% (NO)	yes	91
8.4.7 Sensitivity coefficient of sample gas pressure	≤ 8.0 nmol/mol/kPa	b_{gp} System 1: 0.82 nmol/mol/ kPa (NO) b_{gp} System 2: 0.86 nmol/mol/ kPa (NO)	yes	96
8.4.8 Sensitivity coefficient of sample gas temperature	≤ 3.0 nmol/mol/K	b_{gt} System 1: 0.05 nmol/mol/K (NO) b_{gt} System 2: 0.09 nmol/mol/K (NO)	yes	98
8.4.9 Sensitivity coefficient of surrounding temperature	≤ 3.0 nmol/mol/K	b_{st} System 1: 0.581 nmol/mol/K (NO) b_{st} System 2: 0.269 nmol/mol/K (NO)	yes	100

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 0.00 nmol/mol/V (NO) b_v System 2: RP 0.01 nmol/mol/V (NO)	yes	103
8.4.11 Interferent at zero and at concentration level c_t	H_2O ≤ 5.0 nmol/mol CO_2 ≤ 5.0 nmol/mol NH_3 ≤ 5.0 nmol/mol	NO channel - H_2O System 1: ZP 1.2 nmol/mol / RP -2.40 nmol/mol System 2: ZP 1.0 nmol/mol / RP -1.20 nmol/mol NO channel - CO_2 System 1: ZP -0.60 nmol/mol / RP 1.60 nmol/mol System 2: ZP -0.60 nmol/mol / RP 0.40 nmol/mol NO channel - NH_3 System 1: ZP 0.00 nmol/mol / RP 1.60 nmol/mol System 2: ZP 0.00 nmol/mol / RP 2.00 nmol/mol	yes	105
8.4.12 Averaging effect	≤ 7.0% of the measured value	E_{av} System 1: 0.9% NO E_{av} System 2: -0.3% NO	yes	108
8.4.13 Difference sample/calibration port	≤ 1.0%	Δ_{SC} System 1: -0.19% NO Δ_{SC} System 2: -0.03% NO	yes	111
8.4.3 Response time (rise)	≤ 180 s	t_r System 1: 29 s (NO) t_r System 2: 30 s (NO) t_r System 1: 34 s (NO_2) t_r System 2: 36 s (NO_2)	yes	79
8.4.3 Response time (fall)	≤ 180 s	t_f System 1: 31 s (NO) t_f System 2: 30 s (NO) t_f System 1: 34 s (NO_2) t_f System 2: 34 s (NO_2)	yes	79

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: 0 s (NO) t_d System 1: 0 s (NO_2) t_d System 2: 2 s (NO_2)	yes	79
8.4.14 Converter efficiency	≥ 98%	E_{conv} System 1: 99.2% E_{conv} System 2: 99.3%	yes	113
8.4.15 Residence time	≤ 3.0 s	System 1: 1.5 s System 2: 1.5 s	yes	116
8.5.7 Availability of the analyser	> 90%	A_a System 1: 100% A_a System 2: 100%	yes	124
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: 3.57% NO_2 $S_{r,f}$ System 2: 3.57% NO_2	yes	120
8.5.4 Long-term drift at zero point	≤ 5.0 nmol/mol	$C_{,z}$ System 1: 0.84 nmol/mol NO $C_{,z}$ System 2: 0.96 nmol/mol NO	yes	117
8.5.4 Long-term drift at span level	≤ 5.0% of the upper limit of the certification range	$C_{,s}$ System 1: max. -1.19% NO $C_{,s}$ System 2: max. -1.27% NO	yes	117
8.4.4 Short-term drift at zero	≤ 2.0 nmol/mol over 12 h	$D_{s,z}$ System 1: 0.51 nmol/mol (NO) $D_{s,z}$ System 2: -0.12 nmol/mol (NO)	yes	84
8.4.4 Short-term drift at span level	≤ 6.0 nmol/mol over 12 h	$D_{s,s}$ System 1: -0.87 nmol/mol (NO) $D_{s,s}$ System 2: 1.14 nmol/mol (NO)	yes	84

Table 43: Expanded uncertainty. Laboratory test for NO, system 1

Measuring device:	N200					Serial-No.:	55	
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	0.280	$u_{r,z}$	0.05	0.0026	
2	Repeatability standard deviation at 1h-limit value	≤	3.0 nmol/mol	0.560	$u_{r,lh}$	0.02	0.0005	
3	"lack of fit" at 1h-limit value	≤	4.0% of measured value	0.400	$u_{l,lh}$	0.24	0.0584	
4	Sensitivity coefficient of sample gas pressure at 1h-limit value	≤	8.0 nmol/mol/kPa	0.820	u_{gp}	2.06	4.2574	
5	Sensitivity coefficient of sample gas temperature at 1h-limit value	≤	3.0 nmol/mol/K	0.050	u_{gt}	0.13	0.0158	
6	Sensitivity coefficient of surrounding temperature at 1h-limit value	≤	3.0 nmol/mol/K	0.581	u_{st}	2.19	4.8090	
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_2$0 with 19 mmol/mol	≤	10 nmol/mol (Zero)	1.200	u_{H2O}	0.33	0.1112	
		≤	10 nmol/mol (Span)	-2.400				
8b	Interferent CO_2 with 500 µmol/mol	≤	5.0 nmol/mol (Zero)	-0.600	$u_{int,pos}$ or $u_{int,neg}$	0.19	0.0373	
		≤	5.0 nmol/mol (Span)	1.600				
8c	Interferent NH_3 mit 200 nmol/mol	≤	5.0 nmol/mol (Zero)	0.000				
		≤	5.0 nmol/mol (Span)	1.600				
9	Averaging effect	≤	7.0% of measured value	0.900	u_{av}	0.54	0.2954	
18	Difference sample/calibration port	≤	1.0%	-0.190	$u_{\Delta sc}$	-0.20	0.0395	
21	Converter efficiency	≥	98	99.20	u_{EC}	0.84	0.7002	
23	Uncertainty of test gas	≤	3.0%	2.000	u_{cg}	1.05	1.0941	
			Combined standard uncertainty			u_c	3.3800	nmol/mol
			Expanded uncertainty			U	6.7600	nmol/mol
			Relative expanded uncertainty			W	6.46	%
			Maximum allowed expanded uncertainty			W_{req}	15	%

Table 44: Expanded uncertainty. Laboratory and field tests for NO, system 1

Measuring device:	N200					Serial-No.:	55	
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	0.280	$u_{r,z}$	0.05	0.0026	
2	Repeatability standard deviation at 1h-limit value	≤	3.0 nmol/mol	0.560	$u_{r,lh}$	not considered, as √2*ur,lh = 0,03 < ur,f	-	
3	"lack of fit" at 1h-limit value	≤	4.0% of measured value	0.400	$u_{l,lh}$	0.24	0.0584	
4	Sensitivity coefficient of sample gas pressure at 1h-limit value	≤	8.0 nmol/mol/kPa	0.820	u_{gp}	2.06	4.2574	
5	Sensitivity coefficient of sample gas temperature at 1h-limit value	≤	3.0 nmol/mol/K	0.050	u_{gt}	0.13	0.0158	
6	Sensitivity coefficient of surrounding temperature at 1h-limit value	≤	3.0 nmol/mol/K	0.581	u_{st}	2.19	4.8090	
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_2$0 with 19 mmol/mol	≤	10 nmol/mol (Zero)	1.200	u_{H2O}	0.33	0.1112	
		≤	10 nmol/mol (Span)	-2.400				
8b	Interferent CO_2 with 500 µmol/mol	≤	5.0 nmol/mol (Zero)	-0.600	$u_{int,pos}$ or $u_{int,neg}$	0.19	0.0373	
		≤	5.0 nmol/mol (Span)	1.600				
8c	Interferent NH_3 mit 200 nmol/mol	≤	5.0 nmol/mol (Zero)	0.000				
		≤	5.0 nmol/mol (Span)	1.600				
9	Averaging effect	≤	7.0% of measured value	0.900	u_{av}	0.54	0.2954	
10	Reproducibility standard deviation under field conditions	≤	5.0% of average over 3 months	3.570	$u_{r,f}$	3.73	13.9444	
11	Long term drift at zero level	≤	5.0 nmol/mol	0.840	$u_{d,l,z}$	0.48	0.2352	
12	Long term drift at span level	≤	5.0% of max. of certification range	-1.190	$u_{d,l,lh}$	-0.72	0.5165	
18	Difference sample/calibration port	≤	1.0%	-0.190	$u_{\Delta sc}$	-0.20	0.0395	
21	Converter efficiency	≥	98	99.200	u_{EC}	0.84	0.7002	
23	Uncertainty of test gas	≤	3.0%	2.000	u_{cg}	1.05	1.0941	
			Combined standard uncertainty			u_c	5.1107	nmol/mol
			Expanded uncertainty			U	10.2215	nmol/mol
			Relative expanded uncertainty			W	9.77	%
			Maximum allowed expanded uncertainty			W_{req}	15	%

Table 45: Expanded uncertainty. Laboratory test for NO, system 2

Measuring device:	N200					Serial-No.:	56	
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	0.250	$u_{r,z}$	0.05	0.0021	
2	Repeatability standard deviation at 1h-limit value	≤	3.0 nmol/mol	0.350	$u_{r,lh}$	0.01	0.0002	
3	"lack of fit" at 1h-limit value	≤	4.0% of measured value	1.070	$u_{l,lh}$	0.65	0.4176	
4	Sensitivity coefficient of sample gas pressure at 1h-limit value	≤	8.0 nmol/mol/kPa	0.860	u_{gp}	2.16	4.6829	
5	Sensitivity coefficient of sample gas temperature at 1h-limit value	≤	3.0 nmol/mol/K	0.090	u_{gt}	0.23	0.0513	
6	Sensitivity coefficient of surrounding temperature at 1h-limit value	≤	3.0 nmol/mol/K	0.269	u_{st}	1.02	1.0309	
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_2$0 with 19 mmol/mol	≤	10 nmol/mol (Zero)	0.000	u_{H2O}	0.40	0.1622	
		≤	10 nmol/mol (Span)	0.000				
8b	Interferent CO_2 with 500 µmol/mol	≤	5.0 nmol/mol (Zero)	-0.600	$u_{int,pos}$ or $u_{int,neg}$	0.24	0.0584	
		≤	5.0 nmol/mol (Span)	0.400				
8c	Interferent NH_3 mit 200 nmol/mol	≤	5.0 nmol/mol (Zero)	0.000				
		≤	5.0 nmol/mol (Span)	2.000				
9	Averaging effect	≤	7.0% of measured value	-0.300	u_{av}	-0.18	0.0328	
18	Difference sample/calibration port	≤	1.0%	-0.030	$u_{\Delta sc}$	-0.03	0.0010	
21	Converter efficiency	≥	98	99.30	u_{EC}	0.73	0.5361	
23	Uncertainty of test gas	≤	3.0%	2.000	u_{cg}	1.05	1.0941	
					Combined standard uncertainty	u_c	2.8413	nmol/mol
					Expanded uncertainty	U	5.6827	nmol/mol
					Relative expanded uncertainty	W	5.43	%
					Maximum allowed expanded uncertainty	W_{req}	15	%

Table 46: Expanded uncertainty. Laboratory and field tests for NO, system 2

Measuring device:	N200					Serial-No.:	56	
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	0.250	$u_{r,z}$	0.05	0.0021	
2	Repeatability standard deviation at 1h-limit value	≤	3.0 nmol/mol	0.350	$u_{r,lh}$	not considered, as √2*ur,lh = 0,01 < ur,f	-	
3	"lack of fit" at 1h-limit value	≤	4.0% of measured value	1.070	$u_{l,lh}$	0.65	0.4176	
4	Sensitivity coefficient of sample gas pressure at 1h-limit value	≤	8.0 nmol/mol/kPa	0.860	u_{gp}	2.16	4.6829	
5	Sensitivity coefficient of sample gas temperature at 1h-limit value	≤	3.0 nmol/mol/K	0.090	u_{gt}	0.23	0.0513	
6	Sensitivity coefficient of surrounding temperature at 1h-limit value	≤	3.0 nmol/mol/K	0.269	u_{st}	1.02	1.0309	
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_2$0 with 19 mmol/mol	≤	10 nmol/mol (Zero)	1.000	u_{H2O}	0.40	0.1622	
		≤	10 nmol/mol (Span)	-1.200				
8b	Interferent CO_2 with 500 µmol/mol	≤	5.0 nmol/mol (Zero)	-0.600	$u_{int,pos}$ or $u_{int,neg}$	0.24	0.0584	
		≤	5.0 nmol/mol (Span)	0.400				
8c	Interferent NH_3 mit 200 nmol/mol	≤	5.0 nmol/mol (Zero)	0.000				
		≤	5.0 nmol/mol (Span)	2.000				
9	Averaging effect	≤	7.0% of measured value	-0.300	u_{av}	-0.18	0.0328	
10	Reproducibility standard deviation under field conditions	≤	5.0% of average over 3 months	3.570	$u_{r,f}$	3.73	13.9444	
11	Long term drift at zero level	≤	5.0 nmol/mol	0.960	$u_{d,l,z}$	0.55	0.3072	
12	Long term drift at span level	≤	5.0% of max. of certification range	-1.270	$u_{d,l,lh}$	-0.77	0.5882	
18	Difference sample/calibration port	≤	1.0%	-0.030	$u_{\Delta sc}$	-0.03	0.0010	
21	Converter efficiency	≥	98	99.300	u_{EC}	0.73	0.5361	
23	Uncertainty of test gas	≤	3.0%	2.000	u_{cg}	1.05	1.0941	
					Combined standard uncertainty	u_c	4.7867	nmol/mol
					Expanded uncertainty	U	9.5734	nmol/mol
					Relative expanded uncertainty	W	9.15	%
					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:

- Regular visual inspections/telemetric inspections
- System status checks
- System display checks for error messages
- Zero and span checks performed using suitable test gases every two weeks in accordance with standard EN 14211;

Other than that, the manufacturer's instructions in chapter 5 in the user manual are to be followed.

Environmental Protection/Air Pollution Control

M. Schneid

Dipl.-Ing. Martin Schneider

Guido Baum

Dipl.-Ing. Guido Baum

Cologne, 25 January 2023
936/21255654/A

9. Bibliography

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

10. Annex

Appendix 1	**Certificate of Accreditation to EN ISO/IEC 17025:2018**
Appendix 2	**Weather data during field testing**
Appendix 3	**Results of the "Sensitivity of sample gas pressure" test with the unregulated pump**
Appendix 4	**Results of the test with an alternative particulate filter**
Appendix 5	**Manual**

Appendix 1:

DAkkS
Deutsche
Akkreditierungsstelle

Akkreditierung

Die Deutsche Akkreditierungsstelle bestätigt mit dieser **Teil-Akkreditierungsurkunde**, dass das Prüflaboratorium

TÜV Rheinland Energy GmbH
Am Grauen Stein, 51105 Köln

die Mindestanforderungen gemäß DIN EN ISO/IEC 17025:2018 für die in der Anlage zu dieser Urkunde aufgeführten Konformitätsbewertungstätigkeiten erfüllt.
Dies schließt zusätzliche bestehende gesetzliche und normative Anforderungen ein, einschließlich solcher in relevanten sektoralen Programmen.

Die Anforderungen an das Managementsystem in der DIN EN ISO/IEC 17025 sind in einer für Prüflaboratorien relevanten Sprache verfasst und stehen insgesamt in Übereinstimmung mit den Prinzipien der DIN EN ISO 9001.

Diese Akkreditierung wurde gemäß Art. 5 Abs. 1 Satz 2 VO (EG) 765/2008, nach Durchführung eines Akkreditierungsverfahrens unter Beachtung der Mindestanforderungen der DIN EN ISO/IEC 17011 und auf Grundlage einer Bewertung und Entscheidung durch den eingesetzten Akkreditierungsausschuss ausgestellt.

Diese Teil-Akkreditierungsurkunde gilt nur in Verbindung mit dem Bescheid vom 18.11.2022 mit der Akkreditierungsnummer D-PL-11120-02.
Sie besteht aus diesem Deckblatt, der Rückseite des Deckblatts und der folgenden Anlage mit insgesamt 33 Seiten.

Registrierungsnummer der Teil-Akkreditierungsurkunde: **D-PL-1112-02-01**
Sie ist Bestandteil der Akkreditierungsurkunde D-PL-11120-02-00.

Berlin, 18.11.2022

Im Auftrag Dr. Heike Manke
Abteilungsleitung

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Figure 17: Certificate of accreditation according to EN ISO/IEC 17025:2018 - page 1

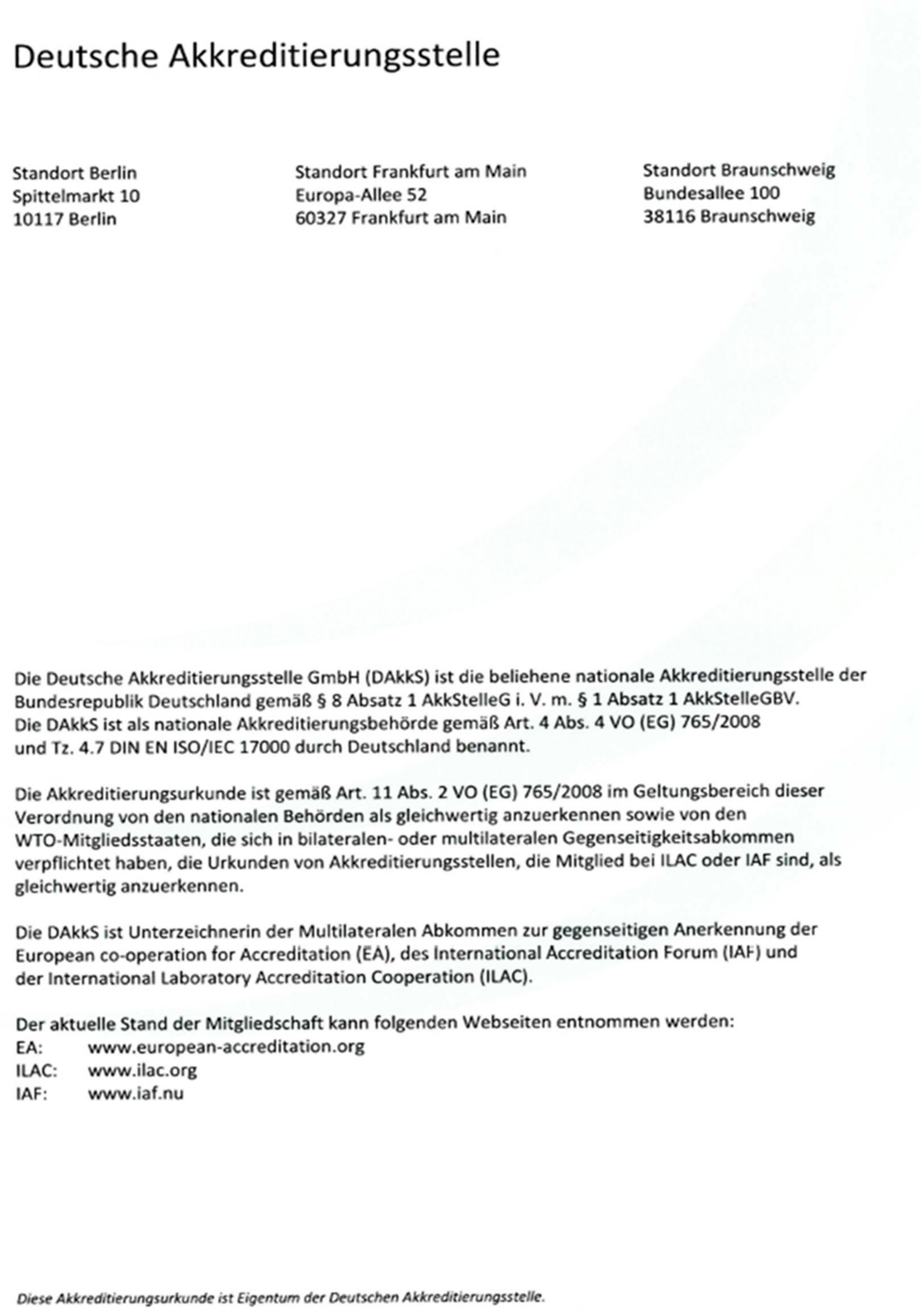

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Figure 17: Certificate of accreditation according to EN ISO/IEC 17025:2018 - page 2

Appendix 2:

Table 47: Weather data (daily averages), May 2022

May 2022	Date	Avg. Air Temp. [°C]	Rel. Humidity [%]	Air pressure [hPa]
17	17.05.2022	19.3	71.3	1014.4
18	18.05.2022	23.5	56.1	1014.1
19	19.05.2022	20.9	71.6	1012.9
20	20.05.2022	18.8	84.6	1012.5
21	21.05.2022	15.8	66.0	1015.3
22	22.05.2022	17.6	62.9	1009.3
23	23.05.2022	18.3	75.9	997.2
24	24.05.2022	14.6	80.1	1001.1
25	25.05.2022	15.6	63.3	1009.8
26	26.05.2022	18.1	62.4	1014.7
27	27.05.2022	15.8	69.2	1015.2
28	28.05.2022	13.3	59.0	1014.6
29	29.05.2022	10.4	78.1	1009.4
30	30.05.2022	11.7	75.4	1007.6
31	31.05.2022	13.7	67.6	1007.3

Table 48: Weather data (daily averages), June 2022

June 2022	Date	Avg. Air Temp. [°C]	Rel. Humidity [%]	Air pressure [hPa]
1	01.06.2022	14.0	66.7	1009.7
2	02.06.2022	15.2	60.9	1014.4
3	03.06.2022	18.7	59.7	1011.0
4	04.06.2022	20.8	65.7	1011.7
5	05.06.2022	19.1	79.0	1008.0
6	06.06.2022	18.3	66.6	1009.3
7	07.06.2022	16.8	78.0	1007.8
8	08.06.2022	16.0	90.3	1003.2
9	09.06.2022	16.2	78.6	1009.0
10	10.06.2022	18.2	71.0	1016.2
11	11.06.2022	21.5	66.6	1016.1
12	12.06.2022	19.8	59.3	1015.9
13	13.06.2022	17.0	60.6	1015.9
14	14.06.2022	17.2	56.1	1015.7
15	15.06.2022	20.7	56.4	1011.4
16	16.06.2022	20.6	52.5	1014.5
17	17.06.2022	23.0	52.5	1016.7
18	18.06.2022	28.4	44.4	1009.9
19	19.06.2022	21.4	61.6	1003.6
20	20.06.2022	16.2	77.8	1008.8
21	21.06.2022	17.2	67.2	1008.4
22	22.06.2022	21.0	58.4	1005.6
23	23.06.2022	25.0	58.7	1004.5
24	24.06.2022	20.6	83.5	1001.8
25	25.06.2022	21.6	67.3	1005.5
26	26.06.2022	18.3	83.8	1009.0
27	27.06.2022	17.9	84.1	1010.7
28	28.06.2022	18.9	67.1	1014.3
29	29.06.2022	20.9	65.2	1008.0
30	30.06.2022	21.5	71.3	1005.3

Table 49: Weather data (daily averages), July 2022

July 2022	Date	Avg. Air Temp. [°C]	Rel. Humidity [%]	Air pressure [hPa]
1	01.07.2022	17.6	70.5	1012.3
2	02.07.2022	20.4	57.0	1014.6
3	03.07.2022	21.1	58.2	1011.9
4	04.07.2022	19.8	55.1	1014.1
5	05.07.2022	19.8	58.2	1015.8
6	06.07.2022	17.5	58.8	1018.8
7	07.07.2022	18.2	67.8	1016.8
8	08.07.2022	19.2	59.7	1023.9
9	09.07.2022	19.7	68.0	1020.4
10	10.07.2022	16.3	73.0	1019.5
11	11.07.2022	18.6	75.2	1017.7
12	12.07.2022	21.3	62.9	1018.2
13	13.07.2022	25.2	52.2	1014.4
14	14.07.2022	21.5	58.5	1013.5
15	15.07.2022	18.7	55.8	1016.1
16	16.07.2022	18.9	55.3	1017.2
17	17.07.2022	20.1	49.5	1020.0
18	18.07.2022	25.2	43.5	1016.1
19	19.07.2022	28.5	40.4	1010.9
20	20.07.2022	26.1	50.7	1010.4
21	21.07.2022	19.0	89.2	1013.5
22	22.07.2022	19.3	77.0	1013.7
23	23.07.2022	21.5	64.4	1012.7
24	24.07.2022	24.8	56.1	1011.4
25	25.07.2022	24.7	53.6	1004.8
26	26.07.2022	20.1	66.2	1010.1
27	27.07.2022	18.1	56.2	1013.2
28	28.07.2022	19.2	55.5	1010.8
29	29.07.2022	21.3	56.4	1009.7
30	30.07.2022	21.5	58.4	1012.4
31	31.07.2022	23.4	57.6	1010.8

Table 50: Weather data (daily averages), August 2022

August 2022	Date	Avg. Air Temp. [°C]	Rel. Humidity [%]	Air pressure [hPa]
1	01.08.2022	22.7	66.0	1011.3
2	02.08.2022	23.6	58.1	1011.5
3	03.08.2022	26.7	52.3	1009.0
4	04.08.2022	26.2	59.7	1006.8
5	05.08.2022	20.0	75.7	1011.4
6	06.08.2022	17.7	56.3	1020.3
7	07.08.2022	18.9	51.2	1018.0
8	08.08.2022	21.3	51.3	1017.9
9	09.08.2022	22.8	52.1	1019.3
10	10.08.2022	24.3	46.5	1017.9
11	11.08.2022	24.8	42.5	1014.8
12	12.08.2022	24.7	40.4	1012.0
13	13.08.2022	25.2	39.0	1009.6
14	14.08.2022	25.5	48.5	1002.5
15	15.08.2022	22.9	60.1	999.3
16	16.08.2022	24.2	57.9	1002.4
17	17.08.2022	22.9	62.8	1004.6
18	18.08.2022	20.9	73.5	1007.3
19	19.08.2022	22.4	66.2	1008.1
20	20.08.2022	21.1	69.3	1010.9
21	21.08.2022	20.5	59.2	1010.7
22	22.08.2022	21.0	56.3	1010.0

Appendix 3:

Evaluation of the sensitivity coefficient of the sample gas pressure according to 7.1 8.4.7 with the alternative pump model (non-regulated pump). See also chapter 3.4.

Table 51: Sensitivity coefficient of the sample gas pressure with the internal pump

	requirement	device 1		device 2	
sensitivity coeff. sample gas pressure b_{gp} [nmol/mol/kPa]	≤ 8,0	0.76	✓	0.82	✓

Table 52: Individual results of the sensitivity to changes in sample gas pressure with the internal pump

time	pressure [kPa]	concentration	device 1 [nmol/mol]	device 2 [nmol/mol]
15:04:00	80	720.0	737.5	738.5
15:05:00	80	720.0	736.8	738.1
15:06:00	80	720.0	736.9	738.5
average C_{P1}			737.1	738.4
15:22:00	110	720.0	713.6	713.4
15:23:00	110	720.0	714.2	713.9
15:24:00	110	720.0	714.6	714.2
average C_{P2}			714.1	713.8

Appendix 4:

Data from the test gas application using the 47 mm round filter after the last drift test at the end of the field test. See also chapter 3.4.

Table 53: Data from the test gas application with alternative particle filter

Average field start $c_{z,0}$		**0.60**	**0.60**
22.08.2022	08:13:00	0.60	0.60
	08:14:00	0.60	0.60
	08:15:00	0.60	0.60
	08:16:00	0.60	0.60
	08:17:00	0.60	0.60
	aver. $c_{z,1}$	**0.60**	**0.60**
22.08.2022	11:42:00	1.20	0.00
	11:43:00	0.60	0.00
	11:44:00	0.60	0.60
	11:45:00	1.20	0.60
	11:46:00	1.20	0.60
	aver. $c_{z,1}$	**0.96**	**0.36**

Average field start $c_{s,0}$		**718.13**	**718.61**
22.08.2022	08:23:00	716.69	718.49
	08:24:00	717.29	718.49
	08:25:00	717.89	718.49
	08:26:00	719.10	718.49
	08:27:00	719.70	719.10
	aver. $c_{s,1}$	**718.13**	**718.61**
22.08.2022	11:54:00	718.52	720.30
	11:55:00	718.52	720.90
	11:56:00	719.10	720.90
	11:57:00	719.10	721.50
	11:58:00	719.10	720.90
	aver. $c_{s,1}$	**718.87**	**720.90**

Appendix 5:

Manual