TÜV RHEINLAND ENERGY GMBH

Deutsche Akkreditierungsstelle
D-PL-11120-02-00

Report on the performance test of the N100 ambient air quality measuring system manufactured by Teledyne API for the component sulphur dioxide

TÜV Report: EuL/21255654/C
Cologne, 28 August 2023

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- sound power levels and noise measurements at wind turbines;

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Report on the performance test of the N100 ambient air quality measuring system manufactured by Teledyne API for the component sulphur dioxide

AMS designation: N100

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

Test period: April 2023 to August 2023

Date of report: 28 August 2023

Report Number: EuL/21255654/C

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Scope of report:

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Manual	pages	132	
Manual	with	176	Pages
Total		308	Pages

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Table of contents

List of tables

List of figures

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1. Summary and certification proposal

1.1 Summary Overview

On behalf of Teledyne API, TÜV Rheinland Energy GmbH carried out performance testing for the N100 AMS for the component sulphur dioxide. The test was performed in respect of the following standards and requirements:

- VDI Guideline 4202 Part 1: Performance test, declaration of suitability, and certification of point-related measuring systems for gaseous air pollutants, April 2018
- EN 14212: Ambient air - Standard method for the measurement of the concentration of sulphur dioxide by ultraviolet fluorescence. November 2012

The N100 measuring system measures the SO_2 component using the ultraviolet fluorescence method. 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 following measuring ranges were tested:

Table 1: Measuring ranges tested

Measured component	Measuring range in [µg/m³] [1]	Measuring range in [ppb] or [nmol/mol]
Sulphur dioxide	0 – 1000	0 – 376

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

During performance testing, the AMS met the requirements specified in standard EN 14212 (2012) and VDI 4202, Part 1 (2018).

TÜV Rheinland Energy GmbH therefore recommends the instrument’s approval as a performance-tested measuring system for the continuous monitoring of ambient air concentrations of sulphur dioxide.

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:

N100 for sulphur dioxide

Manufacturer:

Teledyne API, San Diego, USA

Field of application:

For the continuous measurement of ambient air concentrations of sulphur dioxide in stationary use.

Measuring ranges during performance testing:

Component	Certification range	Unit
Sulphur dioxide	0 - 1000	µg/m³

Software version:

Rev. 1.11.1

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 N100 measuring system can be equipped with a controlled pump (PID controlled), as well as with a non-regulated pump (HD Non-PID).
4. The N100 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

Report no.: EuL/21255654/C dated 28 August 2023

1.3 Summary report on test results

Performance criterion	Requirement	Test result	Satisfied	Page
7 Performance criteria				
7.3 General requirements				
7.3.1 Measured value display	The measuring system shall have an operative measured value display as part of the instrument.	The measuring system has an operative measured value display at the front of the instrument.	yes	33
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	34
7.3.3 Easy maintenance	It should be possible to carry out maintenance work from the outside without major effort.	Maintenance work can be carried out externally with standard tools and reasonable effort.	yes	35
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	36
7.3.5 Set-up times and warm-up times	The instruction manual shall include specifications in this regard.	Set-up times and warm-up times have been determined.	yes	37
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	38
7.3.7 Unintended adjustment	Shall have means of security to this effect.	The measuring system is secured against unintended and unauthorised adjustment of instrument parameters by way of a password.	yes	39
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	40
7.3.9 Digital interface	The digital interface shall allow the transmission of output signals, status signals, and others. Access to the measuring system shall be secured against unauthorised use.	Digital transmission of measured values operates correctly.	yes	41

Performance criterion	Requirement	Test result	Satis-fied	Page
7.3.10 Data transmission protocol	Shall meet the requirements stipulated in Table 1 of VDI Guideline 4202 Part 1.	The measuring system has a Modbus Bavaria/Hesse transmission protocol installed as standard. Measured and status signals are transmitted correctly. The configuration is listed in the manual in Appendix A from page 132.	yes	42
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 - 376 ppb (1000 µg/m³) is set as standard for sulphur dioxide. 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	43
7.3.12 Negative output signals	May not be suppressed (live zero).	The measuring system also provides negative output signals.	yes	44
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. The duration of the warm-up phase depends on the duration of the power failure.	yes	45
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	46
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	47
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	48

Performance criterion	Requirement	Test result	Satis-fied	Page
7.4 Requirements on performance characteristics for testing in the laboratory				
7.4.1 General requirements	The manufacturer's specifications in the instruction manual shall not contradict the results of the performance test.	Tests were performed using the performance characteristics specified in VDI standard 4202, Part 1 (2018) and standard EN 14212 (2012).	yes	49
7.4.2 Test requirements	Has to comply with the requirements set out in VDI standard 4202-1:2018.	Tests were performed using the performance characteristics specified in VDI standard 4202, Part 1 (2018) and standard EN 14212 (2012).	yes	50
Section 8.4 provides a summary of the evaluation of performance characteristics determined in the laboratory.				
7.5 Requirements on performance characteristics for testing in the field				
7.5.1 General requirements	Has to comply with the requirements set out in VDI standard 4202-1:2018.	Tests were performed using the performance characteristics specified in VDI standard 4202, Part 1 (2018) and standard EN 14212 (2012).	yes	65
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	66
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	67
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 14212				
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 system 1 was 54 s and for system 2 was 55 s.	yes	74
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 instrument 1 the value for the short-term drift at zero point was -0.09 nmol/mol/. For instrument 2 it was -0.28 nmol/mol/. Short-term drift at reference point was 1.07 nmol/mol/12 h for instrument 1 and 0.93 nmol/mol/12 h for instrument 2.	yes	78
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 instrument 1 the value for the repeatability standard deviation at zero point was 0.12 nmol/mol. For instrument 2 it was 0.10 nmol/mol. Repeatability standard deviation at reference point was 0.30 nmol/mol for instrument 1 and 0.23 nmol/mol for instrument 2.	yes	82
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 was -0.28 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 -0.70 nmol/mol at zero point and no more than 0.80% of the nominal value for concentrations above zero.	yes	85
8.4.7 Sensitivity coefficient of sample gas pressure	The sensitivity coefficient of sample gas pressure shall be ≤ 2.0 nmol/mol/kPa.	For instrument 1, the sensitivity coefficient of sample gas pressure was 0.39 nmol/mol/kPa. For instrument 2, the sensitivity coefficient of sample gas pressure was 0.40 nmol/mol/kPa.	yes	90

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 ≤ 1.0 µmol/mol/K.	For instrument 1, the sensitivity coefficient of sample gas temperature was 0.05 nmol/mol/K. For instrument 2, the sensitivity coefficient of sample gas temperature was 0.06 nmol/mol/K.	yes	92
8.4.9 Sensitivity coefficient of surrounding temperature	The sensitivity coefficient of the surrounding temperature shall be ≤ 1.0 µmol/mol/K.	The sensitivity coefficient of the surrounding temperature bst did not exceed the performance criterion specified at 1.0 nmol/mol/K. For the purpose of the uncertainty calculation, the largest value bst is used for both instruments. This was 0.347 µmol/mol/K for instrument 1 and 0.356 µmol/mol/K for instrument 2.	yes	94
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 0.3 nmol/mol/V specified in standard EN 14212. For the purpose of the uncertainty calculation, the largest bv is used for both instruments. For system 1 this was: 0.01 nmol/mol/V and for system 2: 0.03 nmol/mol/V.	yes	97
8.4.11 Interferents	Interfering components at zero and at the concentration ct (at the level of the 1-hour limit value = 131 nmol/mol for SO_2). The maximum permitted deviations for the interfering components H_2O and m-xylene are ≤ 10 nmol/mol each and for H_2S, NH_3, NO and NO_2 ≤ 5.0 nmol/mol each.	This results in a value for the cross-sensitivity at zero point of -0.08 nmol/mol for system 1 and 0.00 nmol/mol for system 2 for H_2O, 0.23 nmol/mol for system 1 and 0.16 nmol/mol for system 2 for H_2S, 0.16 nmol/mol for system 1 and -0.16 nmol/mol for system 2 for NH_3, -0.08 nmol/mol for system 1 and 0.00 nmol/mol for system 2 for NO, 0.55 nmol/mol for system 1 and 0.78 nmol/mol for system 2 for NO_2, 0.94 nmol/mol for system 1 and 0.86 nmol/mol for system 2 for m-xylene. For the cross-sensitivity at the limit value ct, this results in a value of 3.21 nmol/mol for system 1 and 2.98 nmol/mol for system 2 for H_2O, -0.47 nmol/mol for system 1 and 0.08 nmol/mol for system 2 for H_2S, 2.35 nmol/mol for system 1 and 2.58 nmol/mol for system 2 for NH_3, 1.18 nmol/mol for system 1 and -1.49 nmol/mol for system 2 for NO, 2.19 nmol/mol for system 1 and 1.65 nmol/mol for system 2 for NO_2, 2.19 nmol/mol for system 1 and 1.41 nmol/mol for system 2 for m-xylene.	yes	99
8.4.12 Averaging test	The averaging effect shall not exceed 7% of the measured value.	The performance criterion specified by standard EN 14212 is fully satisfied.	yes	102

Performance criterion	Requirement	Test result	Satisfied	Page
8.4.13 Difference sample/calibration port	The difference between the sample and calibration ports shall not exceed 1%.	The performance criterion of EN 14212 was fully met with a maximum deviation of -0.14 % and -0.28 % respectively.	yes	105
8.5 Determination of the performance characteristics during the field test according to EN 14212				
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 $D_{l,z}$ was at -1.02 nmol/mol for instrument 1 and -0.63 nmol/mol for instrument 2. Maximum long-term drift at reference point $D_{l,s}$ was at 1.02% for instrument 1 and 0.88% for instrument 2.	yes	107
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 particle filter has to be changed depending on the dust load at the measuring point. A check of the zero and span point must be carried out at least every 14 days in accordance with EN 14212.	yes	113
8.5.5 Reproducibility standard deviation for SO2 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 sulphur dioxide under field conditions was 1.83 % related to the mean value over the duration of the field test of 3 months. Thus, the requirements of EN 14212 are satisfied.	yes	110
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 14212 is satisfied.	yes	114

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 N100 ambient air measuring system. The test was carried out as a complete performance test.

2.2 Objectives

The AMS is designed to determine sulphur dioxide concentrations in ambient air in the following concentration ranges:

Component	Certification range	Unit
Sulphur dioxide	0 - 1000	µg/m³

The N100 measuring system measures the sulphur dioxide component using the ultraviolet fluorescence method.

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

- VDI Guideline 4202 Part 1: Automated measuring systems for air quality monitoring – Performance test, declaration of suitability, and certification of point-related measuring systems for gaseous air pollutants, April 2018
- EN 14212: Ambient air - Standard method for the measurement of the concentration of sulphur dioxide by ultraviolet fluorescence. November 2012

3. Description of the AMS tested

3.1 Measuring principle

The N100 ambient air measuring system is a continuous sulphur dioxide analyser. The measuring principle is based on UV fluorescence. The instrument is designed for the continuous measurement of sulphur dioxide in ambient air.

Figure 1: N100 analyser display

The measurement method is based on the physics principle that fluorescence occurs when sulphur dioxide (SO_2) is excited by UV light with wavelengths in the range of 190 nm - 230 nm (SO_2^*). This reaction is a two-step process: The first step takes place when SO_2 molecules are hit by photons at the correct ultraviolet wavelength. In this analyser, a bandpass filter between the UV light source and the gas to be measured limits the wavelength of the light to around 214 nm. The SO_2 absorbs some of the energy from the UV light, which raises one of the electrons of the SO_2 molecule to a higher energy potential.

$$SO_2 + hv_1 \rightarrow SO_2^* + hv_2$$

The second step of the reaction takes place when the SO_2 reaches its excited state (SO_2^*). As the system always seeks to reach the lowest available stable energy state, the SO_2^* molecule quickly returns to its ground state by releasing the excess energy in the form of a photon ($h\nu$). The wavelength of this fluorescent light is also in the ultraviolet range, but with a longer (energetically lower) wavelength of around 330 nm.

The optical design of the measuring chamber optimises the fluorescence reaction between SO_2 and UV light, ensuring that only the UV light generated by the decay of SO_2* to SO_2 is detected by the device's fluorescence detector.

3.2 AMS scope and set-up

The N100 sulphur dioxide analyser determines the concentration of sulphur dioxide (SO_2) in the sample air drawn into the instrument. The measuring and calibration gases must be supplied at atmospheric pressure so that a constant gas flow can be established through the measuring chamber. The sample gas is then exposed to ultraviolet light in the measuring chamber, which causes the SO_2 to enter an excited state (SO_2*). When the SO_2* molecules then break down to SO_2, they emit fluorescent light. The system measures the amount of fluorescence in order to determine the amount of SO_2 present in the sample gas.

UV radiation is generated by a low pressure zinc vapour lamp designed for maximum generation of light at the wavelength at which SO_2 is excited to SO_2* (214 nm).

A reference detector converts UV light into a DC current, which is used to measure the intensity of the UV excitation source. It is located directly opposite the UV lamp at the end of a narrow tubular light trap and is therefore directly in the path of the UV excitation light. A window that is transparent to UV light forms an airtight seal so that no ambient air can contaminate the measuring chamber. Due to the shape of the light trap and the fact that the detector only recognises UV wavelengths, no further optical filtering is necessary.

The amount of UV fluorescence generated in the measuring chamber is considerably lower than the intensity of the UV excitation lamp. Therefore, a much more sensitive device is needed to detect this light with sufficient resolution: a photomultiplier (PMT) - a vacuum tube with various specially designed electrodes called dynodes. Photons enter the PMT and hit a negatively charged photocathode, causing electrons to be emitted. These electrons are accelerated with a high voltage via a series of dynodes, which increase the number of electrons until a recognisable current signal is generated. The photomultiplier (PMT) detects the UV light (330nm) emitted by the SO_2* decay and outputs an analogue signal.

Multiple focussing lenses and optical filters ensure that both detectors are exposed to the optimum amount of light at just the right wavelength of UV. To ensure that the PMT only recognises the light emitted by the decaying SO_2*, the path of the UV excitation light and the field of view of the PMT are perpendicular to each other. Furthermore, the inner surfaces of the measuring chamber are coated with a layer of black Teflon, which absorbs scattered light.

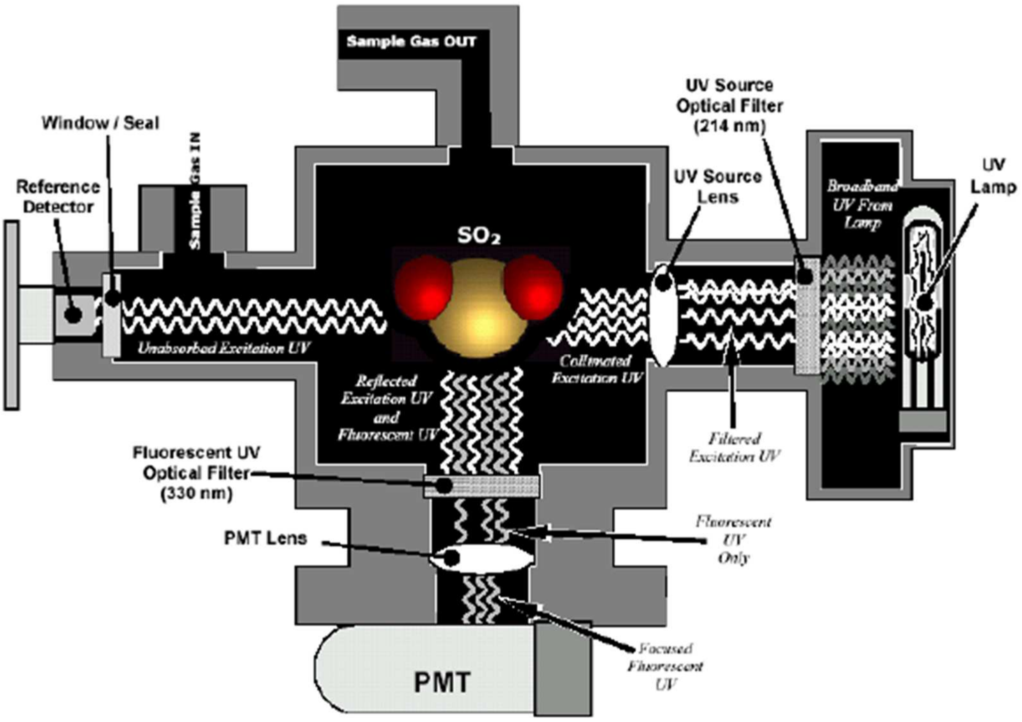


Figure 2: N100 UV light path

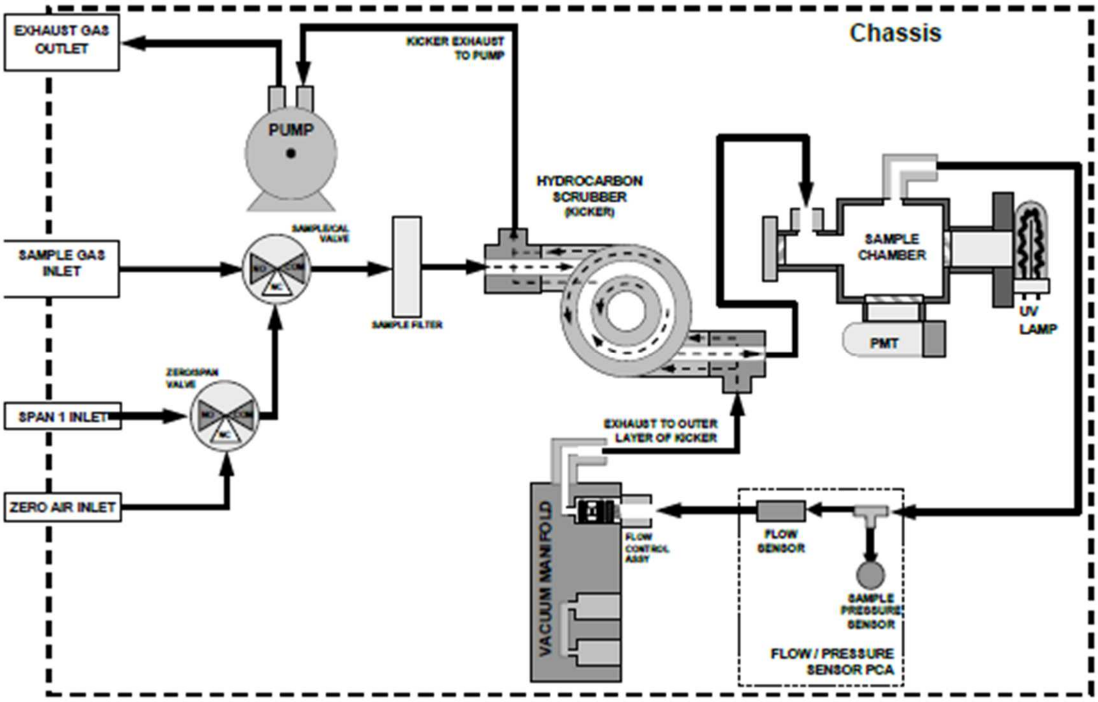


Figure 3: Pneumatic circuit diagram, N100

Components of the analyser

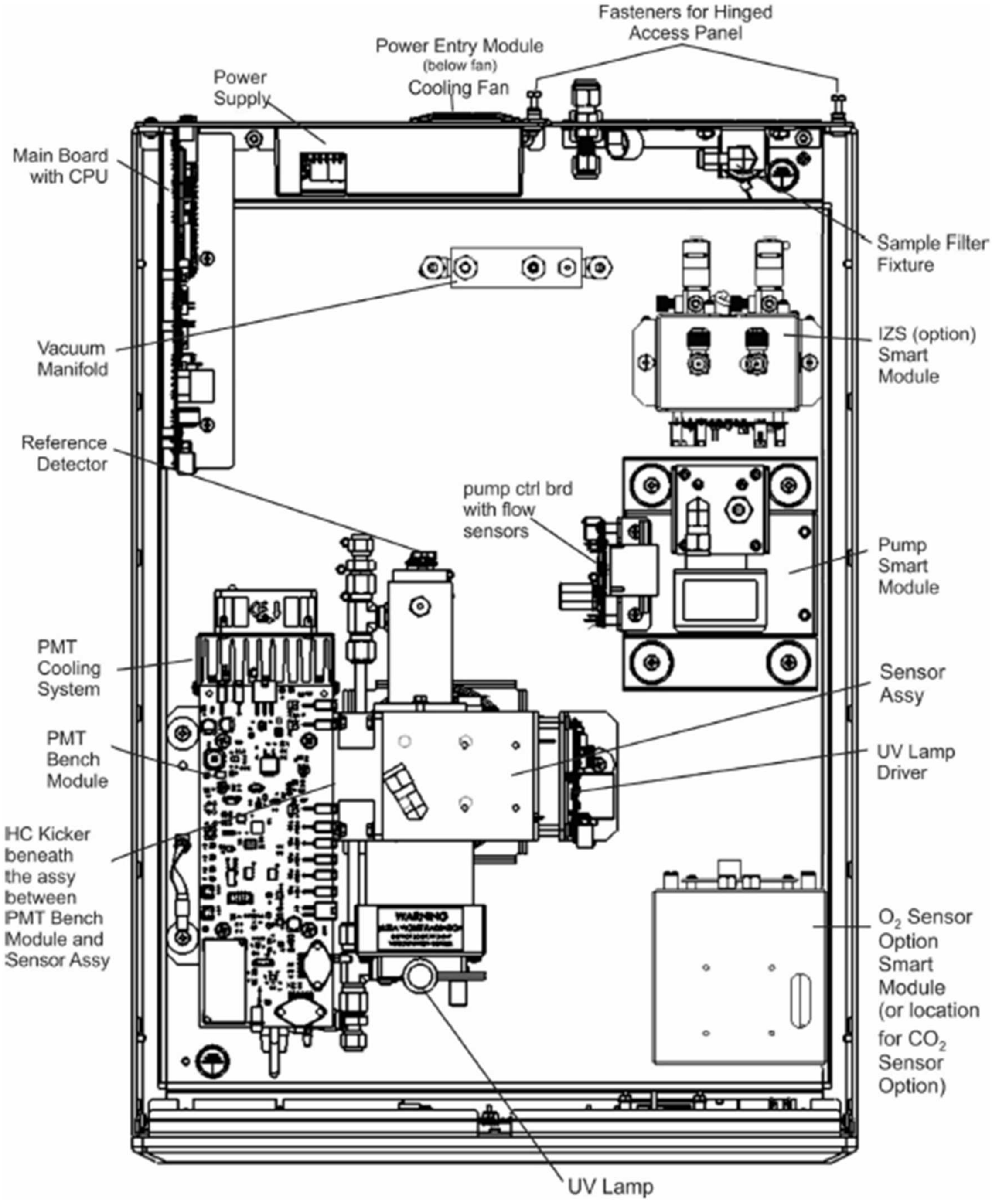


Figure 4: Set-up of the N100 analyser

Table 2 lists a number of important technical specifications of the N100.

Table 2: Technical data N100 (manufacturer's data)

Measured range:	Max 0–20 ppm (selectable)
Units:	ppb, ppm, mg/m³ or µg/m³
Measured compounds:	Sulphur dioxide
Sample flow rate	Approx. 0.7 litre/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:	55 W; 150 W max.
Dimensions (l x w x h) / weight:	617 x 432 x 178 mm / ~ 14 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 N100 analyser firmware processes sample concentration data via a programmed adaptive filter. During operation, the firmware can automatically switch between two different temporal filter lengths depending on the respective conditions. When measuring stable concentrations, the firmware calculates an average of 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 N100 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 N100 measuring system with a DFU filter cartridge with a pore size of 0.01 µm (a so-called long-life filter). The manufacturer specifies a replacement interval of up to 6 months for this 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. The filter can be changed within a few minutes with simple tools for both types of filter.

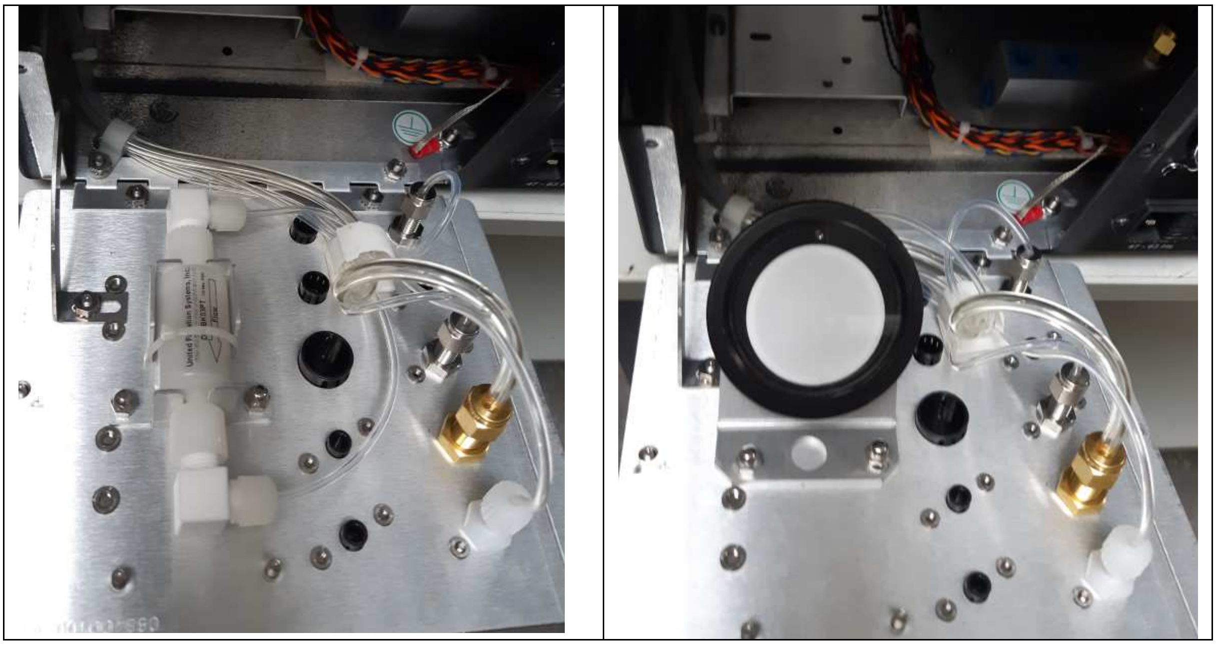


Figure 5: DFU filter (left) and 47 mm round filter (right)

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 N100 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 N100 measuring system.

- The standard pump is an 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 component and thus behind the measuring cell.
- The alternative pump is a regulated pump (PID controlled). This pump regulates itself based on the measured nominal flow rate (700 ml/min). If the flow rate deviates from the set nominal value, the pump adjusts its output accordingly to achieve the nominal flow rate.

Both pump types are controlled via the same control board. When using the "PID Controlled" type, the control must be activated in the software.

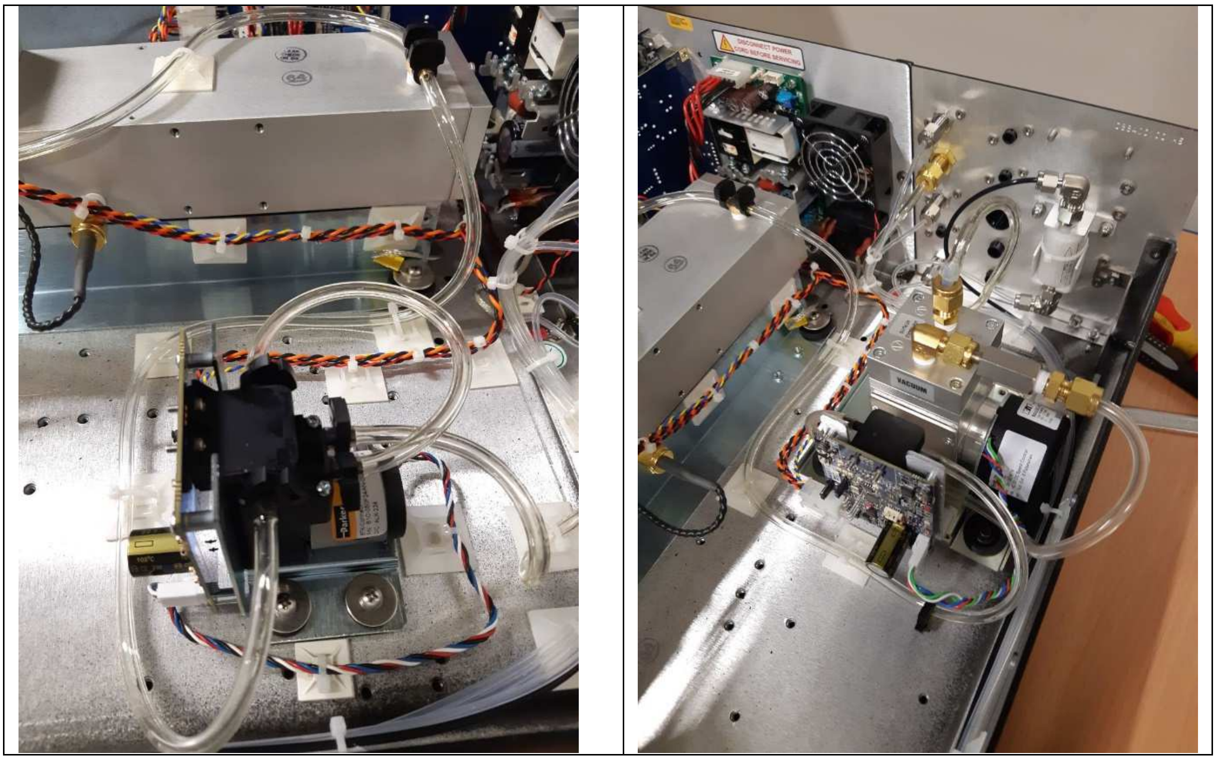


Figure 6: Regulated pump (left) und non-regulated pump (right)

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

After the field test was completed, the unregulated pump was replaced with the regulated pump. Subsequently, the test point "Sensitivity to sample gas pressure" was carried out with the second, controlled pump type.
This test point is also fulfilled by the measuring system when using the second, controlled pump type. The measurement results are shown in appendix 3.

4. Test programme

4.1 General remarks

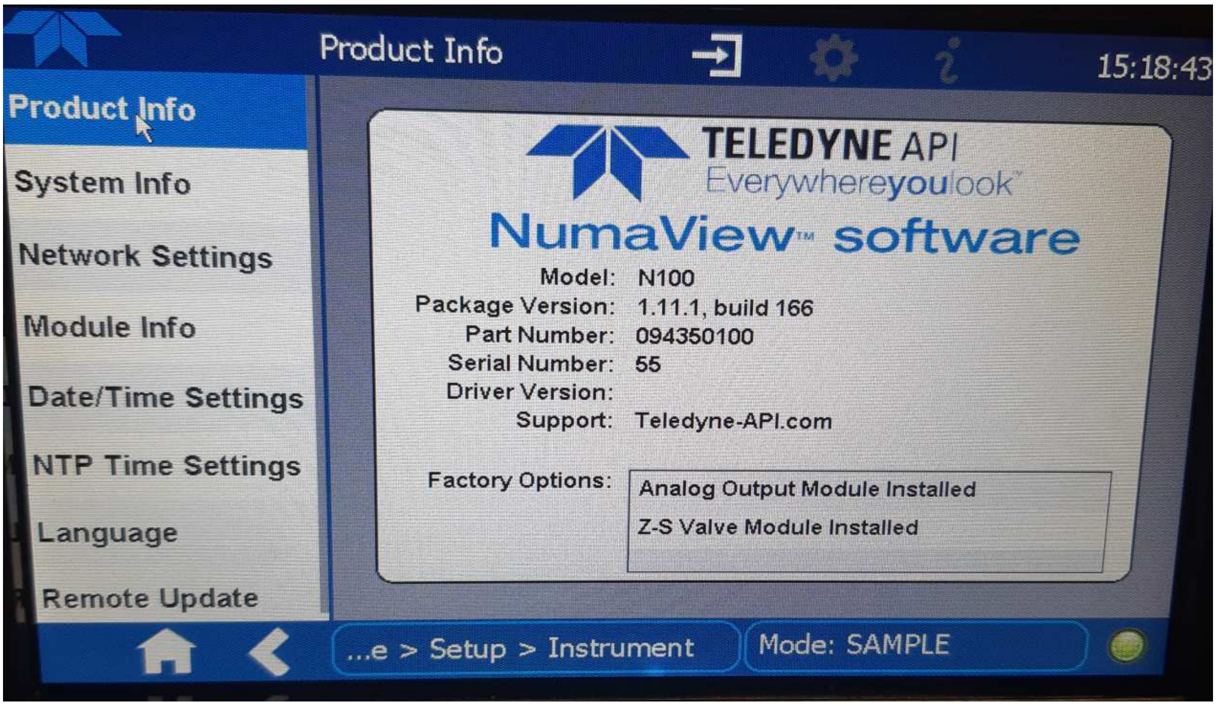
Performance testing was carried out with two identical instruments, type N100, with serial numbers

Instrument 1:	SN 54 and
Instrument 2:	SN 55

Testing was carried out with the software version "Rev. 1.11.1".

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

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



Model: N100
Package Version: 1.11.1, build 166
Part Number: 094350100
Serial Number: 55
Driver Version:
Support: Teledyne-API.com

Factory Options: Analog Output Module Installed
Z-S Valve Module Installed

Figure 7: Software version for the N100 test instruments

4.2 Laboratory test

The laboratory test was carried out with two identical instruments, type N100, with serial numbers SN: 54 and SN: 55. 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

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 14212 and VDI 4202-1 was carried out with two identical N100 measuring systems from 15.05.2023 to 21.08.2023. The instruments used were identical to those used for laboratory testing. The serial numbers were:

Instrument 1:	SN 54
instrument 2:	SN 55

The following test programme was determined for the field test:

- Long-term drift
- Period of unattended operation
- Availability
- Reproducibility standard deviation under field conditions

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 systems carried out a representative measurement of the same sample air volume. The sampling head is located at the front of the measuring station at a total height of approx. 3.00 metres.

Figure 9: N100 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 sulphur dioxide test gases were used to test the performance criteria. The specified test gases were used during the entire test and, where necessary, were diluted with the help of a (Hovacal) mass flow controller.

Test gas bottle (S/N 2008377) 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 SO_2:	**269 ppb in synth. air**
Number of test gas cylinder:	17145
Manufacturer/manufacturing date:	Linde / 09.05.2022
Stability guarantee / certified:	12 months
Checking of the certificate on / by:	14/07/2022 / UBA Langen Calibration certificate No. 022-2022
Measurement uncertainty as per calibration certificate:	+/- 5.4 nmol/mol

Test gas SO_2:	**4.7 ppm in synth. air**
Number of test gas cylinder:	17015
Manufacturer/manufacturing date:	Nippon Gases / 06.05.2021
Stability guarantee / certified:	24 months
Checking of the certificate on / by:	Own laboratory
Rel. uncertainty according to certificate:	2%

Test gas SO_2:	**2.17 ppm in synth. air**
Number of test gas cylinder:	17260
Manufacturer/manufacturing date:	Nippon Gases / 16.03.2023
Stability guarantee / certified:	24 months
Checking of the certificate on / 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 a test specimen with integrated measured value display.

SO2 0.10 PPB

11.5 mV PMT

85.4 % UV Lamp

0.049 PPB SO2 Stability

Mode: SAMPLE

Figure 10: N100 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

Chapter 7.1 8.4.13 Difference sample/calibration port details the functionality of the separate test gas inlet.

6.1 7.3.3 Easy maintenance

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

6.2 Equipment

No additional equipment is required.

6.3 Testing

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

6.4 Evaluation

The user is advised to perform the following maintenance activities:

1. Checking the operational status
   The operational status may be monitored and checked by visual inspections of the instrument's display or via an external PC connected to the AMS.
2. Check the particle filter at the sample gas port. 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 error 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 N100 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 25. The set-up time is specified there as approx. one hour.

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 49).

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

6.5 Assessment

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

It is possible to operate the measuring system at different locations with limited effort. The set-up time is approx. 0.5 - 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

Operating manual as well as a measuring device for recording energy consumption 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 measuring system is specified by the manufacturer as 55 watts. During start-up (warm-up) a short-term consumption of 150 W was recorded. In normal operation, the consumption is approx. 55 watts as specified.

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

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

6.5 Assessment

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

Criterion satisfied? yes

6.6 Detailed presentation of test results

Not required for this performance criterion.

6.1 7.3.8 Data output

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

6.2 Equipment

Analogue Yokogawa data logger, PC

6.3 Testing

The measuring system provides the following transmission routes: Modbus, RS232, RS485, USB, digital outputs, TCP/IP network. Moreover, the measuring system also provides an option to output analogue signals (V or mA).

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.

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 system parameters is password-protected.

6.5 Assessment

Digital transmission of measured values operates correctly.

Criterion satisfied? yes

6.6 Detailed presentation of test results

Not required for this performance criterion.

6.1 7.3.10 Data transmission protocol

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

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

6.2 Equipment

PC

6.3 Testing

The measuring system has an installed Modbus Bavaria/Hesse transmission protocol as standard. Other data transfer protocols are available in consultation with the manufacturer.

6.4 Evaluation

The measuring system has a Modbus Bavaria/Hesse 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 Bavaria/Hesse transmission protocol installed as standard. Measured and status signals are transmitted correctly. The configuration is listed in the manual in Appendix A from page 132.

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.

Possible measuring range:	20 ppm
Upper limit of the certification range for SO_2:	1000 µg/m³ (376 ppb)

6.5 Assessment

A measuring range of 0 - 376 ppb (1000 µg/m³) is set as standard for sulphur dioxide. 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

VDI Guideline 4202, part 1 and standard EN 14212 define the following minimum requirements for the certification ranges of continuous air quality monitoring systems for sulphur dioxide:

Table 3: Certification ranges VDI 4202-1 and EN 14212

Measured component	CR lower limit	CR upper limit	Limit value	Evaluation period
	in µg/m³	in µg/m³	in µg/m³	
Sulphur dioxide	0	1000	350	1 h

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. The duration of the warm-up phase depends on the duration of the power failure.

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

PC

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

It is possible to monitor and control the AMS on the instrument itself or telemetrically.

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. It can also be viewed at any time via the "Product Information" menu.

Testing was carried out with the software version "Rev. 1.11.1".

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 14212 (2012).

6.4 Evaluation

Not applicable.

6.5 Assessment

Tests were performed using the performance characteristics specified in VDI standard 4202, Part 1 (2018) and standard EN 14212 (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 14212 (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 corresponding particle filters. 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.

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

Tests were performed using the performance characteristics specified in VDI standard 4202, Part 1 (2018) and standard EN 14212 (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 14212 (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 14212 (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 14212 (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 14212 (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 2.0 (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 14212 (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 1.0 (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 14212 (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 1.0 (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 of the surrounding temperature in accordance with standard EN 14212 (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 14212 (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 14212 (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

Not applicable

6.3 Testing

Performing and evaluating the averaging effect corresponds exactly to determining the averaging test in accordance with standard EN 14212 (2012).
However, according to VDI 4202-1 (2018), a concentration between zero and 301 nmol/mol sulphur dioxide should be specified to determine the averaging effect. According to EN 14212 (2012), the test of the averaging effect should be carried out between zero and the concentration c_t (1h limit = 131 nmol/mol). For reasons of clarity and for better comparability with previously approved systems, this test was carried out in accordance with the concentration specifications in EN 14212. Furthermore, the value used is closer to the SO_2 concentrations usually measured in Central Europe. The reader is therefore referred to chapter 7.1 8.4.12 Averaging test.

6.4 Evaluation

See chapter 7.1 8.4.12 Averaging test
.

6.5 Assessment

See chapter 7.1 8.4.12 Averaging test
Criterion satisfied? yes

6.6 Detailed presentation of test results

Not applicable in this instance.

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 14212 (2012). Please therefore refer to chapter 7.1 8.4.13 Difference sample/calibration port.

6.4 Evaluation

See chapter 7.1 8.4.13 Difference sample/calibration port

6.5 Assessment

See chapter 7.1 8.4.13 Difference sample/calibration port

Criterion satisfied? yes

6.6 Detailed presentation of test results

Not applicable in this instance.

6.1 7.4.14 Converter efficiency

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

6.2 Equipment

Not applicable

6.3 Testing

The tested measuring system does not use a converter.

6.4 Evaluation

Not applicable.

6.5 Assessment

Not applicable as the measuring system does not use a converter.

Criterion satisfied? Not applicable

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

The instrument tested here is not an NO_x or ozone measuring system. Thus, this criterion does not apply.

6.4 Evaluation

Not applicable.

6.5 Assessment

As the measuring instrument does not measure NO_x or ozone, this test criterion does not apply.

Criterion satisfied? not applicable

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 14212 (2012).

6.4 Evaluation

Not applicable.

6.5 Assessment

Tests were performed using the performance characteristics specified in VDI standard 4202, Part 1 (2018) and standard EN 14212 (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 4.0 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 14212 (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 14212 (2012). Please therfore refer to chapter 7.1 8.5.5 Reproducibility standard deviation for SO_2 under field conditions.

6.4 Evaluation

See chapter 7.1 8.5.5 Reproducibility standard deviation for SO_2 under field conditions

6.5 Assessment

See chapter 7.1 8.5.5 Reproducibility standard deviation for SO_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 14212 (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 14212 (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

Not applicable

6.3 Testing

The tested measuring system does not use a converter.

6.4 Evaluation

Not applicable.

6.5 Assessment

Not applicable as the measuring system does not use a converter.
Criterion satisfied? not applicable

6.6 Detailed presentation of test results

Not applicable in this instance.

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 14212 (2012) and is presented in 7.1 8.6 Calculation of the total uncertainty in accordance with standard EN 14212 (2012) according to Annex E of EN 14212 (2012)

6.4 Evaluation

The uncertainty calculation was performed in line with standard EN 14212 (2012) and is presented in 7.1 8.6 Calculation of the total uncertainty in accordance with standard EN 14212 (2012) according to Annex E of EN 14212 (2012)

6.5 Assessment

The uncertainty calculation was performed in line with standard EN 14212 (2012) and is presented in 7.1 8.6 Calculation of the total uncertainty in accordance with standard EN 14212 (2012) according to Annex E of EN 14212 (2012)

Criterion satisfied? yes

6.6 Detailed presentation of test results

Not applicable in this instance.

7. Test results in accordance with standard EN 14212 (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 Test procedure

The determination of the response time shall be carried out by applying to the analyser a step function in the applied concentration from less than 20 % to about 80 % of the maximum of the certification range 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.

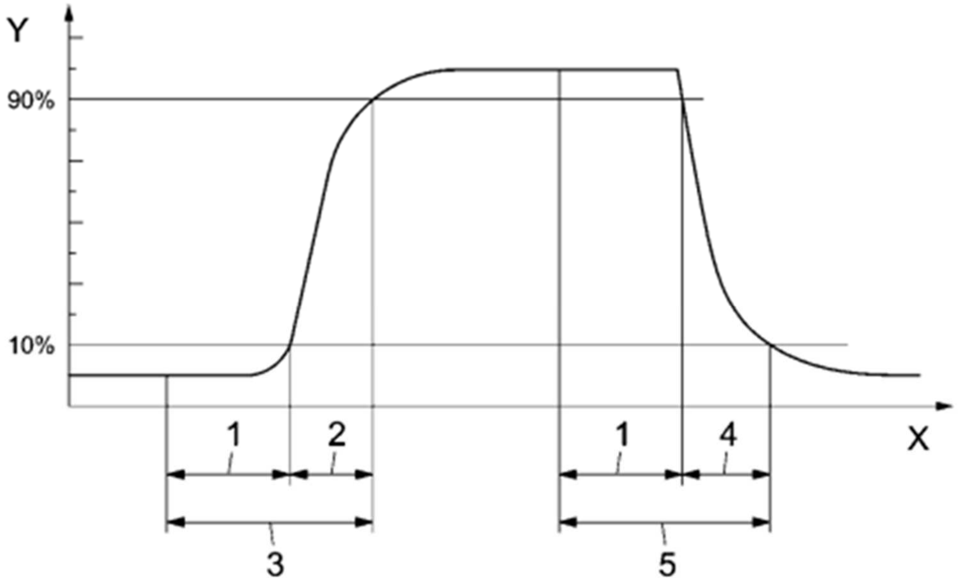
The elapsed time (response time) between the start of the step change and reaching 90% of the analyser final stable reading of the applied concentration shall be measured. The whole cycle shall be repeated four times. The average of the four response times (rise) and the average of the four response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

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

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

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

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



Key

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

Figure 11: Diagram illustrating the response time

7.3 Testing

The test was performed in line with the requirements of EN 14212 mentioned previously. An external data logger was used to record data.

7.4 Evaluation

Table 4: Response times of the N100 measuring system for sulphur dioxide

	requirement	device 1		device 2	
average rise t_r [s]	≤ 180 s	54	✓	55	✓
average fall t_f [s]	≤ 180 s	53	✓	55	✓
difference t_d [s]	≤ 10 s	1,0	✓	0,0	✓

For sulphur dioxide, system 1, the maximum t_r was 54 s, the maximum t_f was 53 s and t_d 1 s.
For sulphur dioxide, system 2, the maximum t_r was 55 s, the maximum t_f was 55 s and t_d 0 s.

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 system 1 was 54 s and for system 2 was 55 s.

Criterion satisfied? yes

7.6 Detailed presentation of test results

Table 5: Individual results of the response time for sulphur dioxide

			device 1				
	80%		rise			fall	
measuring range	300,75	0,0 0,00	0,9 270,68	1,0 300,75	1,0 300,75	0,1 30,08	0,0 0,00
cycle 1	t = 0	13:19:00	13:19:54	13:20:00	13:26:00	13:26:51	13:27:00
	delta t		00:00:54			00:00:51	
	delta t [s]		54			51	
cycle 2	t = 0	13:33:00	13:33:55	13:34:00	13:40:00	13:40:52	13:41:00
	delta t		00:00:55			00:00:52	
	delta t [s]		55			52	
cycle 3	t = 0	13:47:00	13:47:51	13:48:00	13:54:00	13:54:56	13:55:00
	delta t		00:00:51			00:00:56	
	delta t [s]		51			56	
cycle 4	t = 0	14:01:00	14:01:56	14:02:00	14:08:00	14:08:53	14:09:00
	delta t		00:00:56			00:00:53	
	delta t [s]		56			53	

			device 2				
	80%		rise			fall	
measuring range	300,75	0,0 0,00	0,9 270,68	1,0 300,75	1,0 300,75	0,1 30,08	0,0 0,00
cycle 1	t = 0	13:19:00	13:19:51	13:20:00	13:26:00	13:26:57	13:27:00
	delta t		00:00:51			00:00:57	
	delta t [s]		51			57	
cycle 2	t = 0	13:33:00	13:33:57	13:34:00	13:40:00	13:40:55	13:41:00
	delta t		00:00:57			00:00:55	
	delta t [s]		57			55	
cycle 3	t = 0	13:47:00	13:47:56	13:48:00	13:54:00	13:54:52	13:55:00
	delta t		00:00:56			00:00:52	
	delta t [s]		56			52	
cycle 4	t = 0	14:01:00	14:01:56	14:02:00	14:08:00	14:08:56	14:09:00
	delta t		00:00:56			00:00:56	
	delta t [s]		56			56	

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 Test procedure

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 14212 mentioned previously. Pursuant to EN 14212, the test shall be performed at a concentration level of 70% to 80% of the certification range for sulphur dioxide.

7.4 Evaluation

Table 6 shows the measured values determined for the short-term drift.

Table 6: Results for the short-term drift

	requirements	device 1		device 2	
averange at zero at the beginning [nmol/mol]	-	0.18		0.07	
averange at zero at the end (12h) [nmol/mol]	-	0.08		-0.21	
averange at span at the beginning [nmol/mol]	-	280.50		280.51	
averange at span at the end (12h) [nmol/mol]	-	281.47		281.15	
12-hour drift at zero $D_{s,z}$ [nmol/mol]	≤ 2,0	-0.09	✓	-0.28	✓
12-hour drift at span $D_{s,s}$ [nmol/mol]	≤ 6,0	1.07	✓	0.93	✓

7.5 Assessment

For instrument 1 the value for the short-term drift at zero point was -0.09 nmol/mol/. For instrument 2 it was -0.28 nmol/mol/.

Short-term drift at reference point was 1.07 nmol/mol/12 h for instrument 1 and 0.93 nmol/mol/12 h for instrument 2.

Criterion satisfied? yes

7.6 Detailed presentation of test results

Table 7 and Table 8 present the individual test results.

Table 7: Individual results for short-term drift. 1st test gas application

at beginning		
zero level		
27.04.2023	device 1	device 2
time	[nmol/mol]	[nmol/mol]
15:05:00	0.2	0.5
15:06:00	0.2	0.5
15:07:00	0.2	0.0
15:08:00	0.5	0.2
15:09:00	0.2	0.2
15:10:00	0.2	0.0
15:11:00	0.2	0.0
15:12:00	0.2	0.0
15:13:00	0.2	0.0
15:14:00	0.2	0.0
15:15:00	0.0	0.0
15:16:00	0.0	0.0
15:17:00	0.0	0.0
15:18:00	0.0	0.0
15:19:00	0.0	0.0
15:20:00	0.2	0.0
15:21:00	0.2	0.0
15:22:00	0.0	0.0
15:23:00	0.2	0.0
15:24:00	0.2	0.0
average	**0.2**	**0.1**

at beginning		
span level		
27.04.2023	device 1	device 2
time	[nmol/mol]	[nmol/mol]
15:45:00	280.1	279.7
15:46:00	280.6	279.7
15:47:00	280.6	280.1
15:48:00	280.8	280.1
15:49:00	281.1	280.4
15:50:00	281.3	280.4
15:51:00	281.3	280.6
15:52:00	281.1	281.1
15:53:00	280.6	280.8
15:54:00	280.4	281.1
15:55:00	280.4	281.1
15:56:00	279.9	281.1
15:57:00	279.9	280.8
15:58:00	279.9	280.8
15:59:00	279.9	280.8
16:00:00	279.9	280.8
16:01:00	280.4	280.6
16:02:00	280.4	280.4
16:03:00	280.6	280.1
16:04:00	281.1	279.9
average	**280.5**	**280.5**

Table 8: Individual results for short-term drift. 2nd test gas application

after 12h		
zero level		
28.04.2023	device 1	device 2
time	[nmol/mol]	[nmol/mol]
03:05:00	0.0	-0.2
03:06:00	0.0	-0.2
03:07:00	0.0	0.0
03:08:00	0.0	-0.2
03:09:00	0.0	-0.2
03:10:00	0.0	-0.2
03:11:00	0.0	-0.2
03:12:00	0.0	-0.2
03:13:00	0.0	-0.2
03:14:00	0.0	-0.2
03:15:00	0.0	-0.2
03:16:00	0.0	-0.2
03:17:00	0.0	-0.2
03:18:00	0.2	-0.2
03:19:00	0.2	0.0
03:20:00	0.2	-0.2
03:21:00	0.2	-0.2
03:22:00	0.2	-0.2
03:23:00	0.2	-0.2
03:24:00	0.2	-0.2
average	**0.1**	**-0.2**

after 12h		
span level		
28.04.2023	device 1	device 2
time	[nmol/mol]	[nmol/mol]
03:45:00	281.3	280.1
03:46:00	281.5	280.4
03:47:00	281.3	280.6
03:48:00	281.5	280.8
03:49:00	281.5	281.1
03:50:00	281.5	281.3
03:51:00	282.2	281.3
03:52:00	282.2	281.5
03:53:00	282.2	281.8
03:54:00	282.2	282.0
03:55:00	282.0	282.0
03:56:00	281.8	281.8
03:57:00	281.5	281.8
03:58:00	281.1	281.8
03:59:00	281.1	281.8
04:00:00	280.6	281.3
04:01:00	280.6	281.1
04:02:00	280.6	280.6
04:03:00	281.1	280.4
04:04:00	281.5	279.9
average	**281.5**	**281.2**

7.1 8.4.5 Repeatability standard deviation

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

7.2 Test procedure

After waiting the time equivalent of one independent reading, 20 individual measurements both at zero concentration and at a test gas concentration (c_t), similar to the 1-hour limit value, 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:

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

Where:

s_r the repeatability standard deviation;

x_i the ith measurement;

$\bar{x}$ 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 (1-hour-limit value).

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:

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

Where:

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

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

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

7.3 Testing

The test was performed in line with the requirements of EN 14212 mentioned previously. Pursuant to EN 14212, the test shall be performed at a concentration level of 131 nmol/mol SO_2.

7.4 Evaluation

Table 9 presents the results for the repeatability standard deviation.

Table 9: Repeatability standard deviation at zero and span point

	requirement	device 1		device 2	
repeatability standard deviation $s_{r,z}$ at zero [nmol/mol]	≤ 1,0	0.12	✓	0.10	✓
repeatability standard deviation $s_{r,ct}$ at c_t [nmol/mol]	≤ 3,0	0.30	✓	0.23	✓
detection limit [nmol/mol]		0.40		0.31	

7.5 Assessment

For instrument 1 the value for the repeatability standard deviation at zero point was 0.12 nmol/mol. For instrument 2 it was 0.10 nmol/mol. Repeatability standard deviation at reference point was 0.30 nmol/mol for instrument 1 and 0.23 nmol/mol for instrument 2.

Criterion satisfied? yes

7.6 Detailed presentation of test results

Table 10 lists the results of individual measurements.

Table 10: Individual results for repeatability standard deviation

zero level		
	device 1	device 2
time	[nmol/mol]	[nmol/mol]
14:24:00	-0.5	-0.7
14:25:00	-0.5	-0.7
14:26:00	-0.5	-0.7
14:27:00	-0.5	-0.7
14:28:00	-0.5	-0.7
14:29:00	-0.7	-0.7
14:30:00	-0.7	-0.7
14:31:00	-0.7	-0.7
14:32:00	-0.7	-0.7
14:33:00	-0.7	-0.9
14:34:00	-0.7	-0.9
14:35:00	-0.7	-0.7
14:36:00	-0.7	-0.7
14:37:00	-0.7	-0.7
14:38:00	-0.7	-0.9
14:39:00	-0.7	-0.9
14:40:00	-0.7	-0.7
14:41:00	-0.7	-0.7
14:42:00	-0.7	-0.7
14:43:00	-0.9	-0.7
average	-0.7	-0.8

c_t level		
	device 1	device 2
time	[nmol/mol]	[nmol/mol]
15:10:00	131.8	132.8
15:11:00	132.1	133.0
15:12:00	132.3	132.8
15:13:00	132.5	132.8
15:14:00	132.3	132.5
15:15:00	132.5	132.3
15:16:00	132.8	132.3
15:17:00	132.5	132.5
15:18:00	132.3	132.3
15:19:00	132.3	132.5
15:20:00	132.3	132.5
15:21:00	132.3	132.5
15:22:00	132.3	132.8
15:23:00	132.1	133.0
15:24:00	131.8	133.0
15:25:00	131.8	133.0
15:26:00	131.8	132.8
15:27:00	131.8	132.8
15:28:00	131.8	132.5
15:29:00	131.8	132.5
average	132.2	132.7

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, 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 14212. 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 performed in line with the requirements of EN 14212 mentioned previously.

7.4 Evaluation

The following linear regressions were established:

Table 11: Deviation from the analytical function for sulphur dioxide

	requirements	device 1		device 2	
largest value of the relative residuals r_{max} [%]	≤ 4,0	0.40	✓	0.80	✓
residual at zero r_z [nmol/mol]	≤ 5,0	-0.28	✓	-0.70	✓

Figure 12 and Figure 13 summarise the results of the group averages for sulphur dioxide.

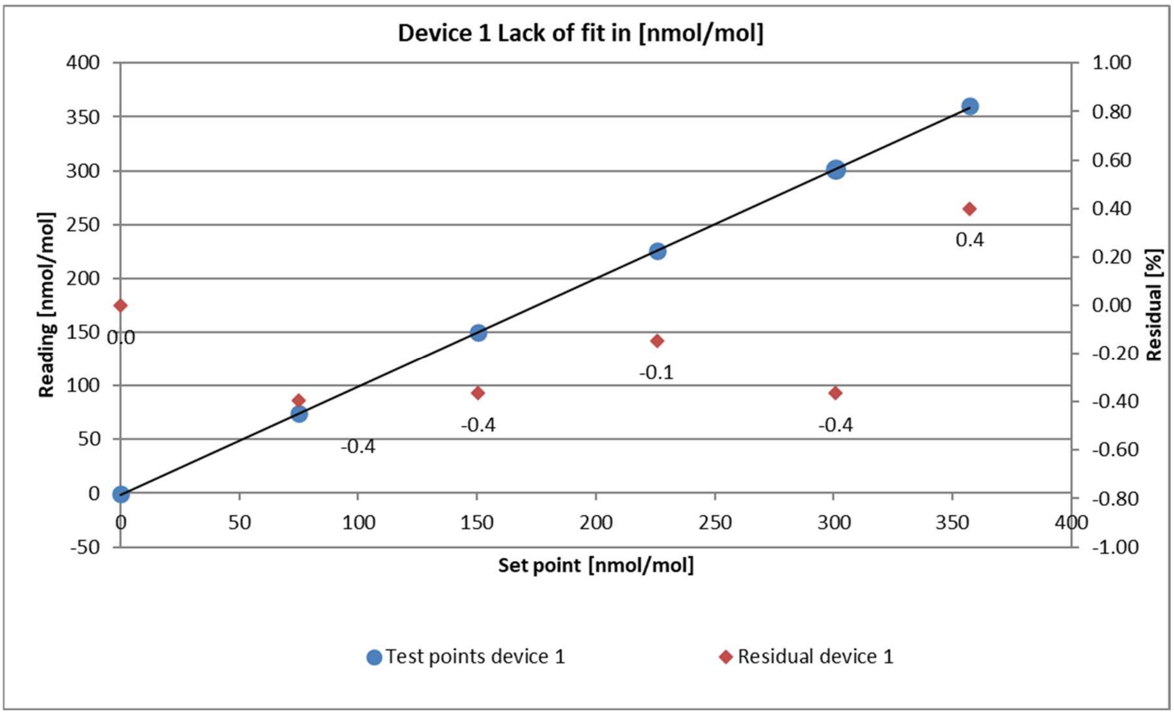


Figure 12: Lack-of-fit results obtained from the group averages for system 1

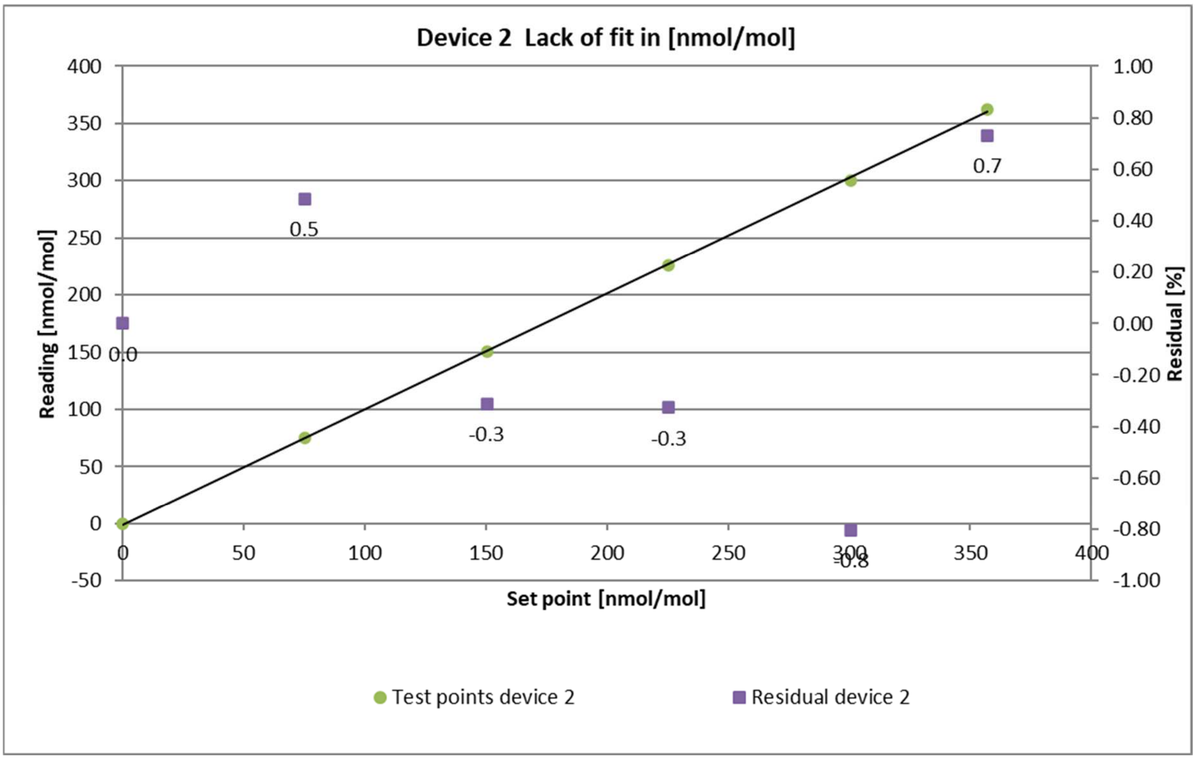


Figure 13: Analytical function obtained from the group averages for system 2

7.5 Assessment

The deviation from the linear regression line for instrument 1 was -0.28 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 -0.70 nmol/mol at zero point and no more than 0.80% 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 14212.

Criterion satisfied? yes

7.6 Detailed presentation of test results

Table 12 presents the individual test results.

Table 12: 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
12:51:00	80	300.10	300.75	299.86	300.75
12:52:00	80	301.04	300.75	300.33	300.75
12:53:00	80	301.74	300.75	300.57	300.75
12:54:00	80	301.27	300.75	300.80	300.75
12:55:00	80	300.33	300.75	301.27	300.75
average		300.89		300.57	
$r_{c,rel}$		-0.37		-0.80	
13:03:00	40	149.46	150.38	150.64	150.38
13:04:00	40	149.70	150.38	150.64	150.38
13:05:00	40	149.93	150.38	150.40	150.38
13:06:00	40	150.17	150.38	150.17	150.38
13:07:00	40	150.17	150.38	149.93	150.38
average		149.88		150.35	
$r_{c,rel}$		-0.36		-0.31	
13:15:00	0	-0.23	0.00	-0.70	0.00
13:16:00	0	-0.23	0.00	-0.70	0.00
13:17:00	0	-0.23	0.00	-0.70	0.00
13:18:00	0	-0.23	0.00	-0.70	0.00
13:19:00	0	-0.47	0.00	-0.70	0.00
average		-0.28		-0.70	
r_z					
13:27:00	60	225.84	225.56	226.31	225.56
13:28:00	60	226.07	225.56	225.84	225.56
13:29:00	60	225.60	225.56	225.84	225.56
13:30:00	60	225.84	225.56	226.31	225.56
13:31:00	60	226.07	225.56	226.54	225.56
average		225.88		226.16	
$r_{c,rel}$		-0.15		-0.33	
13:39:00	20	74.26	75.19	74.97	75.19
13:40:00	20	74.26	75.19	74.97	75.19
13:41:00	20	74.26	75.19	75.20	75.19
13:42:00	20	74.50	75.19	75.20	75.19
13:43:00	20	74.50	75.19	75.20	75.19
average		74.35		75.11	
$r_{c,rel}$		-0.40		0.49	
13:51:00	95	360.49	357.14	361.43	357.14
13:52:00	95	360.26	357.14	361.90	357.14
13:53:00	95	360.02	357.14	362.61	357.14
13:54:00	95	360.26	357.14	363.31	357.14
13:55:00	95	360.26	357.14	364.02	357.14
average		360.26		362.65	
$r_{c,rel}$		0.40		0.73	

7.1 8.4.7 Sensitivity coefficient of sample gas pressure

The sensitivity coefficient of sample gas pressure shall be ≤ 2.0 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 of 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.

7.3 Testing

The test was performed in line with the requirements of EN 14212 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 13: Sensitivity coefficient of the sample gas pressure

	requirement	device 1		device 2	
sensitivity coeff. sample gas pressure b_{gp} [nmol/mol/kPa]	≤ 2,0	0.39	✓	0.40	✓

7.5 Assessment

For instrument 1, the sensitivity coefficient of sample gas pressure was 0.39 nmol/mol/kPa.
For instrument 2, the sensitivity coefficient of sample gas pressure was 0.40 nmol/mol/kPa.

Criterion satisfied? yes

7.6 Detailed presentation of test results

Table 14: Individual results of the sensitivity to changes in sample gas pressure

			device 1	device 2
time	pressure [kPa]	concentration	[nmol/mol]	[nmol/mol]
07:07:00	80	281.95	287.17	286.70
07:08:00	80	281.95	288.11	285.53
07:09:00	80	281.95	287.64	286.47
average C_{P1}			287.64	286.23
07:23:00	110	281.95	276.13	274.25
07:24:00	110	281.95	275.66	274.01
07:25:00	110	281.95	275.89	274.25
average C_{P2}			275.89	274.17

7.1 8.4.8 Sensitivity coefficient of sample gas temperature

The sensitivity coefficient of sample gas temperature shall be ≤ 1.0 µmol/mol/K.

7.2 Test procedures

Measurements shall be performed at sample gas temperatures of $T_{G,1}$ = 0 °C and $T_{G,2}$ = 30 °C. The sensitivity coefficient 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.

7.3 Testing

The test was performed in line with the requirements of EN 14212 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 15: Sensitivity coefficient of the sample gas temperature

	requirement	device 1		device 2	
sensitivity coeff. sample gas temperature b_{gt} [nmol/mol/K]	≤ 1,0	0.05	✓	0.06	✓

7.5 Assessment

For instrument 1, the sensitivity coefficient of sample gas temperature was 0.05 nmol/mol/K.
For instrument 2, the sensitivity coefficient of sample gas temperature was 0.06 nmol/mol/K.
Criterion satisfied? yes

7.6 Detailed presentation of test results

Table 16: Individual results of the influence of the sample gas temperature

			device 1	device 2
time	temp [ºC]	concentration	[nmol/mol]	[nmol/mol]
07:36:00	0	285.00	283.41	283.65
07:37:00	0	285.00	285.29	284.12
07:38:00	0	285.00	284.82	284.59
average $C_{GT,1}$			284.51	284.12
14:20:00	30	285.00	285.53	285.76
14:21:00	30	285.00	286.47	285.29
14:22:00	30	285.00	286.00	286.94
average $C_{GT,2}$			286.00	286.00

7.1 8.4.9 Sensitivity coefficient of surrounding temperature

The sensitivity coefficient of surrounding temperature shall be ≤ 1.0 µmol/mol/K.

7.2 Test procedures

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

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

2) at the laboratory temperature $T_{S,0}$ = 20 °C

3) at the maximum temperature T_{max} = 30 °C (here 45 °C)

For these tests, a climate chamber is necessary.

The sensitivity coefficient of sample gas temperature is determined at zero concentration and a concentration of about 70% to 80% of the maximum of the certification range. At each temperature setting after waiting the time equivalent to one independent measurement, three individual measurements at zero and at span shall be recorded.

The sequence of test temperatures is as follows:

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

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

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

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

Where:

b_{st} is the surrounding temperature sensitivity coefficient;

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

x_1 is the first average of the measurements at $T_{s,0;}$

x_2 is the second average of the measurements at $T_{s,0}$;

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 14212 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 17: Sensitivity coefficient of surrounding temperature

	requirements	device 1		device 2	
sensitivity coefficient at 0 ºC for zero level [nmol/mol/K]	≤ 1,0	0.006	✓	0.006	✓
sensitivity coefficient at 45 ºC for zero level [nmol/mol/K]	≤ 1,0	0.034	✓	0.042	✓
sensitivity coefficient at 0 ºC for span level [nmol/mol/K]	≤ 1,0	0.347	✓	0.356	✓
sensitivity coefficient at 45 ºC for span level [nmol/mol/K]	≤ 1,0	0.296	✓	0.262	✓

As is evident from Table 17, 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 1.0 nmol/mol/K. For the purpose of the uncertainty calculation, the largest value b_{st} is used for both instruments. This was 0.347 µmol/mol/K for instrument 1 and 0.356 µmol/mol/K for instrument 2.

Criterion satisfied? yes

7.6 Detailed presentation of test results

Table 18 presents the individual test results.

Table 18: 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]
02.05.2023	09:45:00	20	-0.5	-0.2	10:05:00	20	279.4	279.9
02.05.2023	09:46:00	20	-0.5	-0.2	10:06:00	20	279.7	280.1
02,05,2023	09:47:00	20	-0.5	-0.2	10:07:00	20	280.1	280.4
average ($X_{1(TS1)}$)			-0.5	-0.2			279.7	280.1
02.05.2023	16:19:00	0	-0.5	-0.2	16:36:00	0	287.6	288.6
02.05.2023	16:20:00	0	-0.5	-0.2	16:37:00	0	288.1	288.8
02.05.2023	16:21:00	0	-0.5	-0.2	16:38:00	0	287.9	288.8
average($X_{Ts,1}$)		0	-0.5	-0.2			287.9	288.7
03.05.2023	06:45:00	20	-0.2	-0.5	06:55:00	20	281.5	283.6
03.05.2023	06:46:00	20	-0.2	-0.5	06:56:00	20	282.5	282.5
03.05.2023	06:47:00	20	-0.2	-0.5	06:57:00	20	282.5	283.2
average ($X_{2(TS1)}$) = ($X_{1(TS2)}$)			-0.2	-0.5			282.2	283.1
03.05.2023	13:49:00	45	0.7	0.7	14:06:00	45	276.1	276.4
03.05.2023	13:50:00	45	0.5	0.7	14:07:00	45	274.2	275.4
03.05.2023	13:51:00	45	0.7	0.7	14:08:00	45	274.2	276.4
average($X_{Ts,2}$)			0.6	0.7			274.9	276.0
04.05.2023	16:07:00	20	-0.2	-0.2	16:19:00	20	282.7	281.8
04.05.2023	16:08:00	20	-0.2	-0.2	16:20:00	20	282.2	282.2
04.05.2023	16:09:00	20	-0.2	-0.2	16:21:00	20	282.2	282.2
average ($X_{2(TS2)}$)			-0.2	-0.2			282.4	282.1

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. 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 14212 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.

7.4 Evaluation

The following sensitivity coefficients of electrical voltage have been determined:

Table 19: 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	0.01	✓	0.03	✓

7.5 Assessment

At no test item did the sensitivity coefficient of electrical voltage b_v exceed the value of 0.3 nmol/mol/V specified in standard EN 14212. For the purpose of the uncertainty calculation, the largest b_v is used for both instruments. For system 1 this was: 0.01 nmol/mol/V and for system 2: 0.03 nmol/mol/V.

Criterion satisfied? yes

7.6 Detailed presentation of test results

Table 20: Individual results of the sensitivity coefficient of electrical voltage

			device 1	device 2
time	voltage [V]	concentration	[nmol/mol]	[nmol/mol]
10:00:00	207	0	0.00	0.00
10:01:00	207	0	0.00	0.00
10:02:00	207	0	0.23	0.00
average C_{V1} at zero			0.08	0.00
10:10:00	253	0	0.23	0.00
10:11:00	253	0	0.23	0.00
10:12:00	253	0	0.23	0.00
average C_{V2} at zero			0.23	0.00
11:05:00	207	284.00	284.35	283.65
11:06:00	207	284.00	284.59	284.12
11:07:00	207	284.00	284.35	284.59
average C_{V1} at Span			284.43	284.12
11:15:00	253	284.00	284.59	285.29
11:16:00	253	284.00	284.59	285.53
11:17:00	253	284.00	285.06	285.29
average C_{V2} at Span			284.74	285.37

7.1 8.4.11 Interferents

Interferents at zero and at the concentration c_t *(at the level of the 1-hour limit = 131 µmol/mol for* SO_2*). The maximum permissible deviations for the interfering components* H_2S*,* NH_3*, NO and* NH_2 *are each ≤ 5.0 µmol/mol. For* H_2O *and m-xylene it is ≤ 10.0 µmol/mol each.*

7.2 Test procedures

The analyser response to certain interferents shall be tested. The interferents can give a positive or negative response. The test is performed at zero concentration and a test gas concentration (c_t) similar to the 1-hour limit (131 µmol/mol for SO_2).

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 21. 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 21. With this mixture, one independent measurement followed by two individual measurements 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 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 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 14212 mentioned previously. The instruments were set at zero and concentration c_t (approximately 131 nmol/mol). Zero and test gas with the various interfering components were then applied. The interferents listed in Table 21 were applied in the concentrations indicated.

Table 21: Interferents in accordance with EN 14212

Interferent	Value
H_2O	19 mmol/mol
H_2S	200 nmol/mol
NH3	200 nmol/mol
NO	500 nmol/mol
NO_2	200 nmol/mol
m-xylene	1 µmol/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 22: Influence of the tested interferents (c_t = 131 nmol/mol)

	requirements	**device 1**		**device 2**	
influence quantity interferent H_2O at zero [nmol/mol/V]	≤ 10.0 µmol/mol	-0.08	✓	0.00	✓
influence quantity interferent H_2O at c_t [nmol/mol/V]	≤ 10.0 µmol/mol	-3.21	✓	-2.98	✓
influence quantity interferent H_2S at zero [nmol/mol/V]	≤ 5.0 µmol/mol	0.23	✓	0.16	✓
influence quantity interferent H_2S at c_t [nmol/mol/V]	≤ 5.0 µmol/mol	-0.47	✓	0.08	✓
influence quantity interferent NH_3 at zero [nmol/mol/V]	≤ 5.0 µmol/mol	0.16	✓	-0.16	✓
influence quantity interferent NH_3 at c_t [nmol/mol/V]	≤ 5.0 µmol/mol	-2.35	✓	-2.58	✓
influence quantity interferent NO at zero [nmol/mol/V]	≤ 5.0 µmol/mol	-0.08	✓	0.00	✓
influence quantity interferent NO at c_t [nmol/mol/V]	≤ 5.0 µmol/mol	-1.18	✓	-1.49	✓
influence quantity interferent NO_2 at zero [nmol/mol/V]	≤ 5.0 µmol/mol	0.55	✓	0.78	✓
influence quantity interferent NO_2 at c_t [nmol/mol/V]	≤ 5.0 µmol/mol	2.19	✓	1.65	✓
influence quantity interferent m-Xylol at zero [nmol/mol/V]	≤ 10.0 µmol/mol	0.94	✓	0.86	✓
influence quantity interferent m-Xylol at c_t [nmol/mol/V]	≤ 10.0 µmol/mol	2.19	✓	1.41	✓

7.5 Assessment

This results in a value for the cross-sensitivity at zero point of -0.08 nmol/mol for system 1 and 0.00 nmol/mol for system 2 for H_2O, 0.23 nmol/mol for system 1 and 0.16 nmol/mol for system 2 for H_2S, 0.16 nmol/mol for system 1 and -0.16 nmol/mol for system 2 for NH_3, -0.08 nmol/mol for system 1 and 0.00 nmol/mol for system 2 for NO, 0.55 nmol/mol for system 1 and 0.78 nmol/mol for system 2 for NO_2, 0.94 nmol/mol for system 1 and 0.86 nmol/mol for system 2 for m-xylene.

For the cross-sensitivity at the limit value c_t, this results in a value of -3.21 nmol/mol for system 1 and -2.98 nmol/mol for system 2 for H_2O, -0.47 nmol/mol for system 1 and 0.08 nmol/mol for system 2 for H_2S, -2.35 nmol/mol for system 1 and -2.58 nmol/mol for system 2 for NH_3, -1.18 nmol/mol for system 1 and -1.49 nmol/mol for system 2 for NO, 2.19 nmol/mol for system 1 and 1.65 nmol/mol for system 2 for NO_2, 2.19 nmol/mol for system 1 and 1.41 nmol/mol for system 2 for m-xylene.

Criterion satisfied? yes

7.6 Detailed presentation of test results

Table 23 presents the individual test results.

Table 23: 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)	08:17:00	-0.70	-0.70	0.36	-0.70	-0.70
	08:18:00	-0.70	-0.70	0.36	-0.70	-0.70
	08:19:00	-0.47	-0.70	0.36	-0.70	-0.70
	average x_z	-0.63	-0.70	average x_z	-0.70	-0.70
test gas c_t + H_2O (19 mmol/mol)	08:48:00	132.78	132.07	0.38	130.19	129.72
	08:49:00	132.54	133.01	0.38	129.25	129.49
	08:50:00	133.25	132.54	0.38	129.49	129.49
	average x_{ct}	132.85	132.54	average x_{ct}	129.64	129.56
zero gas + H_2S (200 nmol/mol)	13:56:00	-0.23	-0.23	0.59	-0.23	0.00
	13:57:00	-0.23	-0.23	0.59	0.00	0.00
	13:58:00	-0.47	-0.23	0.59	0.00	-0.23
	average x_z	-0.31	-0.23	average x_z	-0.08	-0.08
test gas c_t + H_2S (200 nmol/mol)	08:46:00	133.25	133.01	0.38	132.78	133.01
	08:47:00	133.25	133.01	0.38	132.78	133.01
	08:48:00	133.25	133.01	0.38	132.78	133.25
	average x_{ct}	133.25	133.01	average x_{ct}	132.78	133.09
zero gas + NH_3 (200 nmol/mol)	14:24:00	0.00	0.00	0.61	0.00	0.00
	14:25:00	-0.23	0.00	0.61	0.00	-0.23
	14:26:00	-0.23	0.00	0.61	0.00	-0.23
	average x_z	-0.16	0.00	average x_z	0.00	-0.16
test gas c_t + NH_3 (200 nmol/mol)	07:48:00	133.48	133.01	0.34	130.90	130.43
	07:49:00	133.48	133.01	0.34	131.13	130.43
	07:50:00	133.25	133.01	0.34	131.13	130.43
	average x_{ct}	133.40	133.01	average x_{ct}	131.05	130.43
zero gas + NO_2 (200 nmol/mol)	14:43:00	0.23	0.00	0.63	0.00	-0.23
	14:44:00	0.23	0.00	0.63	0.00	0.00
	14:45:00	0.00	-0.23	0.63	0.23	0.00
	average x_z	0.16	-0.08	average x_z	0.08	-0.08
test gas c_t + NO_2 (200 nmol/mol)	07:20:00	131.84	131.60	0.32	132.54	132.31
	07:21:00	132.07	131.84	0.32	132.31	132.31
	07:22:00	132.78	132.31	0.32	132.31	132.31
	average x_{ct}	132.23	131.91	average x_{ct}	132.38	132.31
zero gas + NO (500 nmol/mol)	13:28:00	0.00	-0.23	0.57	0.71	0.71
	13:29:00	0.00	-0.23	0.57	0.47	0.47
	13:30:00	0.00	-0.23	0.57	0.47	0.47
	average x_z	0.00	-0.23	average x_z	0.55	0.55
test gas c_t + NO (500 nmol/mol)	09:18:00	133.48	133.01	0.40	135.60	134.89
	09:19:00	133.25	133.25	0.40	135.60	134.89
	09:20:00	133.25	133.25	0.40	135.36	134.66
	average x_{ct}	133.32	133.17	average x_{ct}	135.52	134.81
zero gas + m-Xylol (1 µmol/mol)	12:59:00	0.00	-0.23	0.55	0.94	0.71
	13:00:00	0.00	-0.23	0.55	0.94	0.71
	13:01:00	-0.23	-0.23	0.55	0.71	0.47
	average x_z	-0.08	-0.23	average x_z	0.86	0.63
test gas c_t + m-Xylol (1 µmol/mol)	08:17:00	132.07	131.60	0.36	134.19	133.01
	08:18:00	132.07	131.60	0.36	134.42	133.25
	08:19:00	132.07	132.07	0.36	134.19	133.25
	average x_{ct}	132.07	131.76	average x_{ct}	134.26	133.17

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 sulphur dioxide concentration between zero and the concentration c_t

The time span (t_c) of the constant sulphur dioxide concentrations must be at least equal to that required to obtain four independent readings (corresponding to at least 16 response times). The time period (t_v) of the varying sulphur dioxide concentration shall be at least equal to a period to obtain four independent readings. The time period (t_{SO2}) for the sulphur dioxide 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 the total number of t_{SO2} and t_{zero} pairs, (at least 3 such pairs.)

The change from t_{O3} to t_{zero} shall be within 0.5 s. The change from t_C to t_V shall be within one response time of the analyser under test.

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

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

Where:

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

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

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

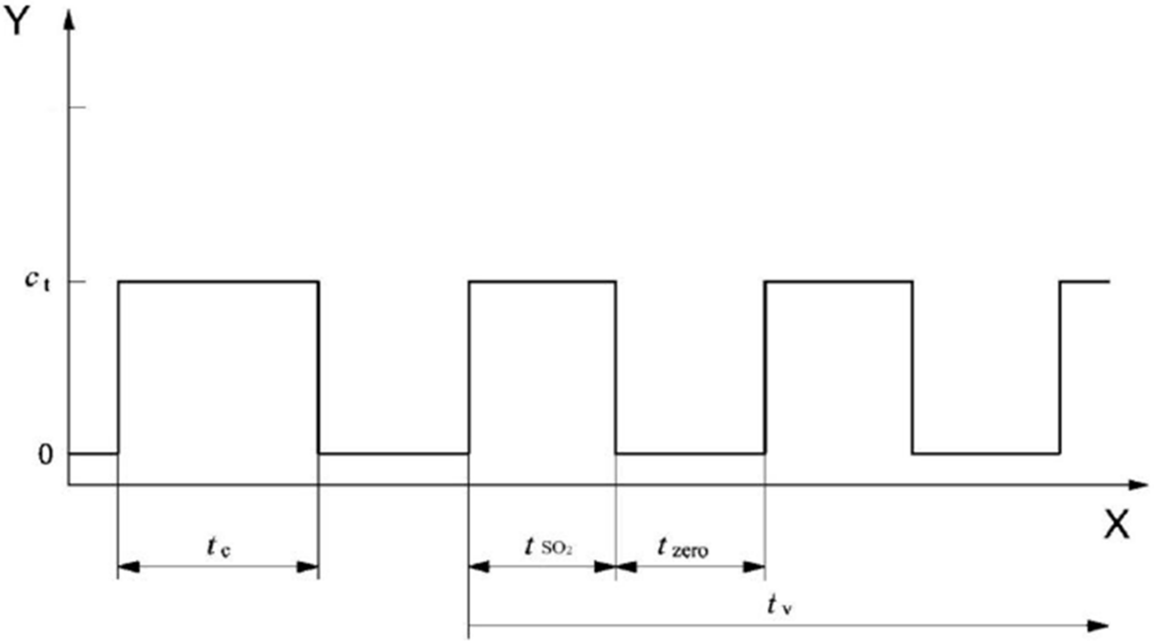


Figure 14: Test of the averaging effect (t_{SO2} = t_{zero} = 45 s.)

7.3 Testing

The averaging test was performed in compliance with the requirements specified in EN 14212. As this is a direct-measuring sulphur dioxide measuring system, this test was carried out with a sulphur dioxide concentration that changed abruptly between zero and the concentration c_t (131 nmol/mol). 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 24: Results of the averaging test

	requirement	device 1		device 2	
averaging effect E_{av} [%]	≤ 7%	-1.2	✓	-1.7	✓

This results in the following averaging effects:

System 1 (12): -1.2 %

System 2 (14): -1.7 %

7.5 Assessment

The performance criterion specified by standard EN 14212 is fully satisfied.

Criterion satisfied? yes

7.6 Detailed presentation of test results

Table 25 presents the individual results of the averaging test.

Table 25: Results of the averaging test

		device 1	device 2
	time	[nmol/mol]	[nmol/mol]
average constant concentration $C_{av,c}$	11:41:00	133.5	133.1
	till		
	12:00:00		
average variable concentration $C_{av,c}$	12:01:00	68.8	68.6
	till		
	12:20:00		

		device 1	device 2
	time	[nmol/mol]	[nmol/mol]
average constant concentration $C_{av,c}$	12:53:00	133.5	133.4
	till		
	13:12:00		
average variable concentration $C_{av,c}$	13:13:00	67.3	68.1
	till		
	13:32:00		

		device 1	device 2
	time	[nmol/mol]	[nmol/mol]
average constant concentration $C_{av,c}$	14:06:00	133.7	133.3
	till		
	14:25:00		
average variable concentration $C_{av,c}$	14:26:00	66.8	66.5
	till		
	14:45:00		

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;

Δx_{SC} shall comply with the performance criterion indicated above.

7.3 Testing

The test was performed in compliance with the requirements specified in EN 14212. 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 26: Results of determining the difference between sample/calibration port

	requirement	device 1		device 2	
difference sample/calibration port Δx_{cs} [%]	≤ 1%	-0.14	✓	-0.28	✓

7.5 Assessment

The performance criterion of EN 14212 was fully met with a maximum deviation of -0.14 % and -0.28 % respectively.

Criterion satisfied? yes

7.6 Detailed presentation of test results

Table 27 presents the individual values.

Table 27: Individual results for testing the difference between sample / calibration port

		device 1	device 2
	time	[nmol/mol]	[nmol/mol]
calibration port	07:43:00	289.1	287.9
	07:44:00	289.1	287.9
	07:45:00	289.1	287.9
sample port	07:54:00	289.3	288.3
	07:55:00	289.5	288.6
	07:56:00	289.5	289.1

7.1 8.5.4 Long-term drift

The long-term drift at zero point shall not exceed ≤ 4.0 nmol/mol.
Long-term drift at span level shall not exceed 5% of the certification range.

7.2 Test procedures

After each two-week zero and span gas test, the drift of the measuring instruments under test shall be calculated at zero and span level in accordance with the procedures specified in this section. If the drift compared to the initial calibration exceeds one of the performance criteria for drift at zero or span level, the “period of unattended operation” equals the number of weeks until the observation of the infringement, minus two weeks. For further (uncertainty) calculations, the values for “long term drift” are the values for zero and span drift over the period of unattended operation.

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

The long-term drift is calculated as follows:

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

Where:

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

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

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

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

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

Where:

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

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

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

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

7.3 Testing

For the purpose of this test, test gas was applied every other week. Table 28 and Table 29 report the measured values for bi-weekly test gas applications.

7.4 Evaluation

Table 28: Results for the long-term drift at zero point

		requierment	Device 1		Device 2	
average start $Cz_{,1}$ at zero [nmol/mol]	15.05.2023	≤ 5,0	--	✓	--	✓
long term drift $D_{L,Z}$ at zero [nmol/mol]	30.05.2023	≤ 5,0	-1.02	✓	-0.63	✓
long term drift $D_{L,Z}$ at zero [nmol/mol]	12.06.2023	≤ 5,0	-0.03	✓	-0.16	✓
long term drift $D_{L,Z}$ at zero [nmol/mol]	26.06.2023	≤ 5,0	-0.31	✓	-0.34	✓
long term drift $D_{L,Z}$ at zero [nmol/mol]	10.07.2023	≤ 5,0	-0.08	✓	-0.16	✓
long term drift $D_{L,Z}$ at zero [nmol/mol]	24.07.2023	≤ 5,0	0.11	✓	-0.02	✓
long term drift $D_{L,Z}$ at zero [nmol/mol]	07.08.2023	≤ 5,0	-0.17	✓	-0.16	✓
long term drift $D_{L,Z}$ at zero [nmol/mol]	21.08.2023	≤ 5,0	-0.08	✓	0.03	✓

Table 29: Results for the long-term drift at span point

		requierment	Device 2 1		Device 2	
average start $Cs_{,1}$ at span [nmol/mol]	15.05.2023	≤ 5 %	--	✓	--	✓
long term drift $D_{L,S}$ at span [nmol/mol]	30.05.2023	≤ 5 %	0.08	✓	0.02	✓
long term drift $D_{L,S}$ at span [nmol/mol]	12.06.2023	≤ 5 %	-0.12	✓	0.12	✓
long term drift $D_{L,S}$ at span [nmol/mol]	26.06.2023	≤ 5 %	0.18	✓	0.34	✓
long term drift $D_{L,S}$ at span [nmol/mol]	10.07.2023	≤ 5 %	0.33	✓	0.55	✓
long term drift $D_{L,S}$ at span [nmol/mol]	24.07.2023	≤ 5 %	0.48	✓	0.59	✓
long term drift $D_{L,S}$ at span [nmol/mol]	07.08.2023	≤ 5 %	0.79	✓	0.88	✓
long term drift $D_{L,S}$ at span [nmol/mol]	21.08.2023	≤ 5 %	1.02	✓	0.83	✓

7.5 Assessment

Maximum long-term drift at zero point $D_{l,z}$ was at -1.02 nmol/mol for instrument 1 and -0.63 nmol/mol for instrument 2. Maximum long-term drift at reference point $D_{l,s}$ was at 1.02% for instrument 1 and 0.88% for instrument 2.

Criterion satisfied? yes

7.6 Detailed presentation of test results

Table 30 presents the individual values obtained for the determination of the long-term drift.

Table 30: Individual results for the drift tests

Zero Concentration			
		Device 1	Device 2
Date	Time	[nmol/mol]	[nmol/mol]
15.05.2023	11:46:00	0.23	0.23
	11:47:00	0.23	0.23
	11:48:00	0.23	0.00
	Mittel	0.23	0.16
	11:50:00	0.47	0.00
	11:51:00	0.47	0.00
	11:52:00	0.47	0.23
	Mittel	0.47	0.08
	11:54:00	0.47	0.23
	11:55:00	0.47	0.23
	11:56:00	0.23	0.23
	Mittel	0.39	0.23
	11:58:00	0.23	0.00
	11:59:00	0.23	0.00
	12:00:00	0.23	0.23
	Mittel	0.23	0.08
	12:02:00	0.23	0.23
	12:03:00	0.23	0.23
	12:04:00	0.23	0.23
		0.23	0.23
Average field start $c_{z,0}$		**0.31**	**0.16**
30.05.2023	12:56:00	-0.70	-0.47
	12:57:00	-0.70	-0.47
	12:58:00	-0.70	-0.47
	12:59:00	-0.70	-0.47
	13:00:00	-0.70	-0.47
	aver. $c_{z,1}$	**-0.70**	**-0.47**
12.06.2023	12:02:00	0.23	0.00
	12:03:00	0.23	0.00
	12:04:00	0.23	0.00
	12:05:00	0.23	0.00
	12:06:00	0.47	0.00
	aver. $c_{z,1}$	**0.28**	**0.00**
26.06.2023	08:52:00	0.00	-0.23
	08:53:00	0.00	-0.23
	08:54:00	0.00	0.00
	08:55:00	0.00	-0.23
	08:56:00	0.00	-0.23
	aver. $c_{z,1}$	**0.00**	**-0.19**
10.07.2023	08:43:00	0.23	0.00
	08:44:00	0.23	0.00
	08:45:00	0.23	0.00
	08:46:00	0.23	0.00
	08:47:00	0.23	0.00
	aver. $c_{z,1}$	**0.23**	**0.00**
24.07.2023	08:38:00	0.23	0.23
	08:39:00	0.47	0.23
	08:40:00	0.47	0.23
	08:41:00	0.47	0.00
	08:42:00	0.47	0.00
	aver. $c_{z,1}$	**0.42**	**0.14**
07.08.2023	11:56:00	0.23	0.00
	11:57:00	0.23	0.00
	11:58:00	0.23	0.00
	11:59:00	0.00	0.00
	12:00:00	0.00	0.00
	aver. $c_{z,1}$	**0.14**	**0.00**
21.08.2023	08:53:00	0.23	0.00
	08:54:00	0.23	0.23
	08:55:00	0.23	0.23
	08:56:00	0.23	0.23
	08:57:00	0.23	0.23
	aver. $c_{z,1}$	**0.23**	**0.19**

C_t-Concentration			
		Device 1	Device 2
Date	Time	[nmol/mol]	[nmol/mol]
15.05.2023	12:13:00	281.77	282.00
	12:14:00	281.53	281.77
	12:15:00	281.30	281.53
	Mittel	281.53	281.77
	12:17:00	281.77	282.71
	12:18:00	281.77	281.53
	12:19:00	282.00	281.77
	Mittel	281.84	282.00
	12:21:00	281.77	281.53
	12:22:00	282.00	281.53
	12:23:00	282.24	282.00
	Mittel	282.00	281.69
	12:25:00	281.77	281.77
	12:26:00	281.77	281.53
	12:27:00	281.77	281.53
	Mittel	281.77	281.61
	12:29:00	281.53	281.53
	12:30:00	281.77	281.53
	12:31:00	281.77	281.53
		281.69	281.53
Average field start $c_{s,0}$		**281.77**	**281.72**
30.05.2023	13:09:00	280.36	280.83
	13:10:00	280.83	281.06
	13:11:00	281.53	281.77
	13:12:00	280.83	281.06
	13:13:00	281.30	281.06
	aver. $c_{s,1}$	**280.97**	**281.15**
12.06.2023	12:32:00	281.53	282.24
	12:33:00	281.30	281.77
	12:34:00	281.53	282.00
	12:35:00	281.30	281.77
	12:36:00	281.30	281.77
	aver. $c_{s,1}$	**281.39**	**281.91**
26.06.2023	09:22:00	282.47	282.71
	09:23:00	282.24	282.71
	09:24:00	281.77	282.24
	09:25:00	281.77	282.24
	09:26:00	281.53	281.77
	aver. $c_{s,1}$	**281.95**	**282.33**
10.07.2023	09:12:00	282.47	282.94
	09:13:00	282.71	283.18
	09:14:00	282.71	283.18
	09:15:00	282.47	283.18
	09:16:00	282.71	283.18
	aver. $c_{s,1}$	**282.61**	**283.13**
24.07.2023	09:10:00	282.71	282.94
	09:11:00	282.71	282.94
	09:12:00	283.18	283.41
	09:13:00	284.82	284.82
	09:14:00	282.71	282.71
	aver. $c_{s,1}$	**283.22**	**283.36**
07.08.2023	12:30:00	283.88	283.88
	12:31:00	284.12	284.12
	12:32:00	283.88	284.12
	12:33:00	283.65	284.12
	12:34:00	283.65	284.12
	aver. $c_{s,1}$	**283.83**	**284.07**
21.08.2023	09:30:00	284.35	284.12
	09:31:00	284.59	284.12
	09:32:00	284.59	284.12
	09:33:00	284.82	284.12
	09:34:00	284.59	284.12
	aver. $c_{s,1}$	**284.59**	**284.12**

7.1 8.5.5 Reproducibility standard deviation for SO_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 sulphur 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.

As the ambient air in Central Europe usually has a sulphur dioxide concentration close to zero, the sample air was enriched with sulphur dioxide in various concentrations over a period of 7 days. This served to demonstrate that the measuring systems work identically even at higher concentrations. For the purpose of enrichment, a small amount of highly concentrated test gas was dispensed into the sampling system of the measuring station using a needle valve. Apart from the sulphur dioxide concentration, the gas matrix was barely changed with regard to humidity, pressure, temperature and the other measurable air constituents.

7.4 Evaluation

Table 31: Determination of the reproducibility standard deviation based on complete field test data

reproducibility standard deviation in field		
no. of measurments (1h- average)	[n]	2350
average of both analyzers (3 month)	[nmol/mol]	9.49
standard deviation from paired measurements	[nmol/mol]	0.174
reproducibility standard deviation in field $S_{r,f}$	**[%]**	**1.83**
requirement	≤ 5,0 %	✓

The reproducibility standard deviation under field conditions is at 1.83% of the average.

7.5 Assessment

The reproducibility standard deviation for sulphur dioxide under field conditions was 1.83 % related to the mean value over the duration of the field test of 3 months. Thus, the requirements of EN 14212 are satisfied.

Criterion satisfied? yes

7.6 Detailed presentation of test results

Figure 15 provides an illustration of the reproducibility standard deviation under field conditions.

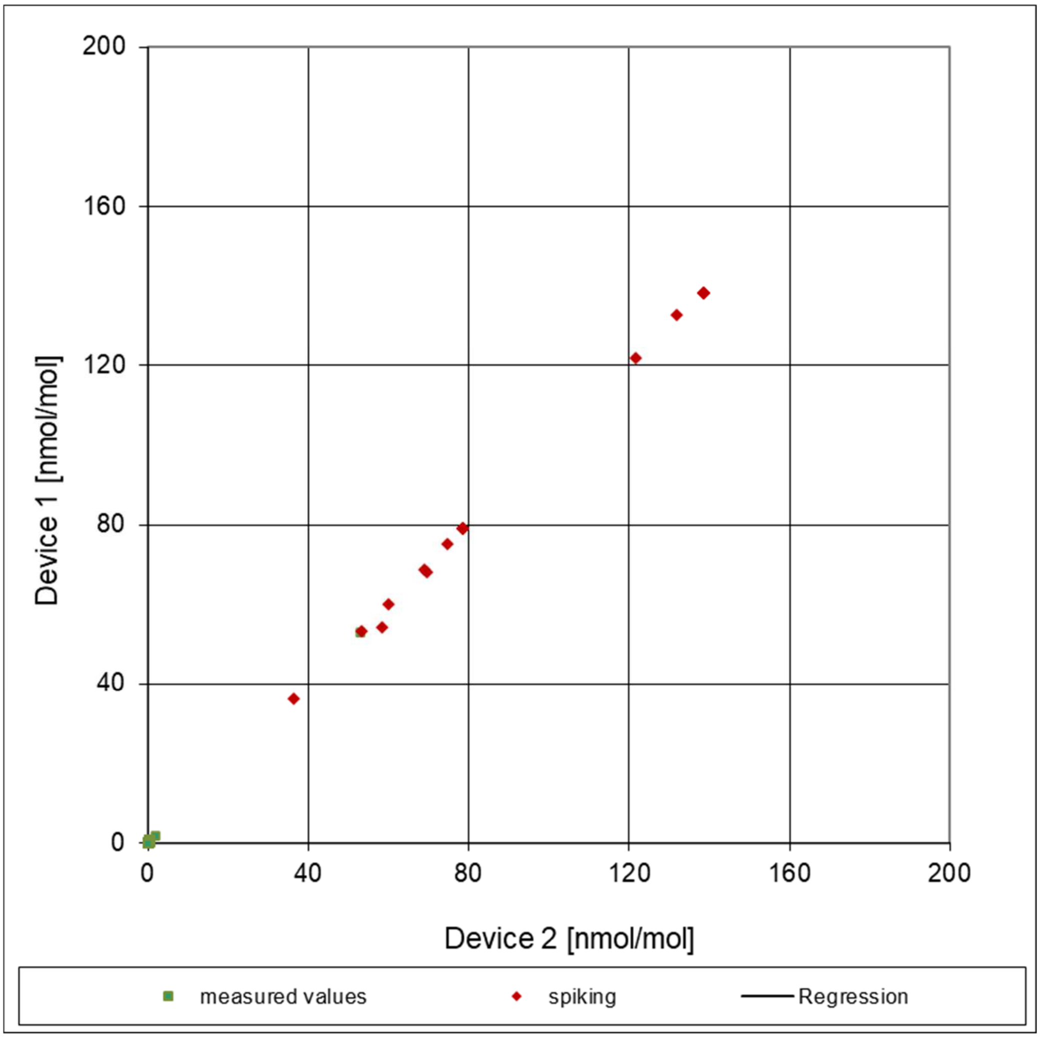


Figure 15: Reproducibility standard deviation under field conditions

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 particle filter has to be changed depending on the dust load at the measuring point. A check of the zero and span point must be carried out at least every 14 days in accordance with EN 14212.

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 32.

Table 32: Availability of the N100 measuring system

		System 1	System 2
Operation time	h	2350	2350
Outage time	h	0	0
Maintenance time	h	8	8
Actual operating time:	h	2342	2342
Actual operating time incl. maintenance times:	h	2350	2350
Availability	%	100	100

The maintenance times result from the daily test gas applications to determine the drift behaviour and the maintenance interval.

7.5 Assessment

The availability was at 100%. Thus, the requirement of EN 14212 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 14212 (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 14212.

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 14212.

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 14212.

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 14212.

7.2 Equipment

Calculation of the total uncertainty in accordance with standard EN 14212 (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 14212.

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 14212.

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 33 summarises the results for items 1 and 3.

Table 34 and Table 36 contain the results regarding item 2.

Table 35 and Table 37 contain the results regarding item 4.

Table 33: Relevant performance characteristics and criteria according to EN 14212

Performance characteristic	Performance criterion	Test result	Satisfied	Page
8.4.5 Repeatability standard deviation at zero	≤ 1.0 nmol/mol	S_r System 1: 0.12 nmol/mol S_r System 2: 0.10 nmol/mol	yes	82
8.4.5 Repeatability standard deviation at concentration level c_t	≤ 3.0 nmol/mol	S_r system 1: 0.30 nmol/mol S_r System 2: 0.23 nmol/mol	yes	82
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 -0.28 nmol/mol X_l System 1: RP 0.40% $X_{l,z}$ System 2: ZP -0.70 nmol/mol X_l System 2: RP 0.80%	yes	85
8.4.7 Sensitivity coefficient of sample gas pressure	≤ 2.0 nmol/mol/kPa	b_{gp} System 1: 0.39 nmol/mol/kPa b_{gp} System 2: 0.40 nmol/mol/kPa	yes	90
8.4.8 Sensitivity coefficient of sample gas temperature	≤ 1.0 nmol/mol/K	b_{gt} System 1: 0.05 nmol/mol/K b_{gt} System 2: 0.06 nmol/mol/K	yes	92
8.4.9 Sensitivity coefficient of surrounding temperature	≤ 1.0 nmol/mol/K	b_{st} System 1: 0.347 nmol/mol/K b_{st} System 2: 0.356 nmol/mol/K	yes	94
8.4.10 Sensitivity coefficient of electrical voltage	≤ 0.3 nmol/mol/V	b_v System 1: RP 0.01 nmol/mol/V b_v System 2: RP 0.03 nmol/mol/V	yes	97
8.4.11 Interferent at zero and at concentration level c_t	H_2O ≤ 10.0 nmol/mol H_2S ≤ 5.0 nmol/mol NH3 ≤ 5.0 nmol/mol	H_2O System 1: ZP -0.08 nmol/mol / RP -3.21 nmol/mol System 2: ZP 0.00 nmol/mol / RP -2.98 nmol/mol H_2S System 1: ZP 0.23 nmol/mol / RP -0.47 nmol/mol System 2: ZP 0.16 nmol/mol / RP 0.08 nmol/mol NH3 System 1: ZP 0.16 nmol/mol / RP -2.35 nmol/mol System 2: ZP -0.16 nmol/mol / RP -2.58 nmol/mol	yes	99

Performance characteristic	**Performance criterion**	**Test result**	**Satisfied**	**Page**
8.4.11 Interferent at zero and at concentration level c_t (continued)	NO ≤ 5.0 nmol/mol NO_2 ≤ 5.0 nmol/mol m-xylene ≤ 10.0 nmol/mol	NO System 1: ZP -0.08 nmol/mol / RP -1.18 nmol/mol System 2: ZP 0.00 nmol/mol / RP -1.49 nmol/mol NO_2 System 1: ZP 0.55 nmol/mol / RP 2.19 nmol/mol System 2: ZP 0.78 nmol/mol / RP 1.65 nmol/mol m-xylene System 1: ZP 0.94 nmol/mol / RP 2.19 nmol/mol System 2: ZP 0.86 nmol/mol / RP 1.41 nmol/mol	**yes**	99
8.4.12 Averaging effect	≤ 7.0% of the measured value	E_{av} System 1: -1.2% E_{av} System 2: -1.7%	yes	102
8.4.13 Difference sample/calibration port	≤ 1.0%	Δ_{SC} System 1: -0.14% Δ_{SC} System 2: -0.28%	yes	105
8.4.3 Response time (rise)	≤ 180 s	t_r system 1: 54 s t_r System 2: 55 s	yes	74
8.4.3 Response time (fall)	≤ 180 s	t_f System 1: 53 s t_f System 2: 55 s	yes	74
8.4.3 Difference between the rise and fall response time	≤ 10 s	t_d System 1: 1.0 s t_d System 2: 0.0 s	yes	74
8.5.7 Availability of the analyser	> 90%	A_a System 1: 100% A_a System 2: 100%	yes	114
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: 1.83% $S_{r,f}$ System 2: 1.83%	yes	110
8.5.4 Long-term drift at zero point	≤ 5.0 nmol/mol	$C_{,z}$ System 1: -1.02 nmol/mol $C_{,z}$ System 2: -0.63 nmol/mol	yes	107
8.5.4 Long-term drift at span level	≤ 5.0% of the upper limit of the certification range	$C_{,s}$ System 1: max. 1.02% $C_{,s}$ System 2: max. 0.88%	yes	107
8.4.4 Short-term drift at zero	≤ 2.0 nmol/mol over 12 h	$D_{s,z}$ System 1: -0.09 nmol/mol $D_{s,z}$ System 2: -0.28 nmol/mol	yes	78
8.4.4 Short-term drift at span level	≤ 6.0 nmol/mol over 12 h	$D_{s,s}$ System 1: 1.07 nmol/mol $D_{s,s}$ System 2: 0.93 nmol/mol	yes	78

Table 34: Expanded uncertainty. Laboratory test for system 1

Measuring device:	N100				Serial-No.:		SN: 54	
Measured component:	SO2				1h-limit value:		132	nmol/mol
No.	**Performance characteristic**	**Performance criterion**		**Result**	**Partial uncertainty**		**Square of partial uncertainty**	
1	Repeatability standard deviation at zero	≤	1.0 nmol/mol	0.120	$u_{r,z}$	0.03	0.0009	
2	Repeatability standard deviation at 1h-limit value	≤	3.0 nmol/mol	0.300	$u_{r,lh}$	0.07	0.0053	
3	"lack of fit" at 1h-limit value	≤	4.0% of measured value	0.400	$u_{l,lh}$	0.30	0.0929	
4	Sensitivity coefficient of sample gas pressure at 1h-limit value	≤	2.0 nmol/mol/kPa	0.390	u_{gp}	3.17	10.0690	
5	Sensitivity coefficient of sample gas temperature at 1h-limit value	≤	1.0 nmol/mol/K	0.050	u_{gt}	0.60	0.3645	
6	Sensitivity coefficient of surrounding temperature at 1h-limit value	≤	1.0 nmol/mol/K	0.347	u_{st}	4.25	18.0632	
7	Sensitivity coefficient of electrical voltage at 1h-limit value	≤	0.30 nmol/mol/V	0.010	u_V	0.09	0.0088	
8a	Interferent H_20 with 19 mmol/mol	≤	10 nmol/mol (Zero)	-0.080	u_{H2O}	-2.40	5.7372	
		≤	10 nmol/mol (Span)	-3.210				
8b	Interferent H_2S with 200 nmol/mol	≤	5.0 nmol/mol (Zero)	0.230	$u_{int,pos}$ or $u_{int,neg}$	3.21	10.3045	
		≤	5.0 nmol/mol (Span)	-0.470				
8c	Interferent NH_3 with 200 nmol/mol	≤	5.0 nmol/mol (Zero)	0.160				
		≤	5.0 nmol/mol (Span)	-2.350				
8d	Interferent NO with 500 nmol/mol	≤	5.0 nmol/mol (Zero)	-0.080				
		≤	5.0 nmol/mol (Span)	1.180				
8e	Interferent NO_2 with 200 nmol/mol	≤	5.0 nmol/mol (Zero)	0.550				
		≤	5.0 nmol/mol (Span)	2.190				
8f	Interferent m-Xylene with 1 µmol/mol	≤	10 nmol/mol (Zero)	0.940				
		≤	10 nmol/mol (Span)	2.190				
9	Averaging effect	≤	7.0% of measured value	-1.200	u_{av}	-0.91	0.8364	
18	Difference sample/calibration port	≤	1.0%	-0.140	$u_{\Delta sc}$	-0.18	0.0342	
21	Uncertainty of test gas	≤	3.0%	2.000	u_{cg}	1.32	1.7424	
					Combined standard uncertainty	u_c	6.8745	nmol/mol
					Expanded uncertainty	U	13.7491	nmol/mol
					Relative expanded uncertainty	W	10.42	%
					Maximum allowed expanded uncertainty	W_{req}	15	%

Table 35: Expanded uncertainty. Laboratory and field tests for system 1

Measuring device:	N100				Serial-No.:		SN: 54	
Measured component:	SO2				1h-limit value:		132	nmol/mol
No.	**Performance characteristic**	**Performance criterion**		**Result**	**Partial uncertainty**		**Square of partial uncertainty**	
1	Repeatability standard deviation at zero	≤	1.0 nmol/mol	0.120	$u_{r,z}$	0.03	0.0009	
2	Repeatability standard deviation at 1h-limit value	≤	3.0 nmol/mol	0.300	$u_{r,lh}$	not considered, as ur,lh = 0.07 < ur,f	-	
3	"lack of fit" at 1h-limit value	≤	4.0% of measured value	0.400	$u_{l,lh}$	0.30	0.0929	
4	Sensitivity coefficient of sample gas pressure at 1h-limit value	≤	2.0 nmol/mol/kPa	0.390	u_{gp}	3.17	10.0690	
5	Sensitivity coefficient of sample gas temperature at 1h-limit value	≤	1.0 nmol/mol/K	0.050	u_{gt}	0.60	0.3645	
6	Sensitivity coefficient of surrounding temperature at 1h-limit value	≤	1.0 nmol/mol/K	0.347	u_{st}	4.25	18.0632	
7	Sensitivity coefficient of electrical voltage at 1h-limit value	≤	0.30 nmol/mol/V	0.010	u_V	0.09	0.0088	
8a	Interferent H_20 with 19 mmol/mol	≤	10 nmol/mol (Zero)	-0.080				
		≤	10 nmol/mol (Span)	-3.210	u_{H2O}	-2.40	5.7372	
8b	Interferent H_2S with 200 nmol/mol	≤	5.0 nmol/mol (Zero)	0.230				
		≤	5.0 nmol/mol (Span)	-0.470	$u_{int,pos}$ or $u_{int,neg}$	3.21	10.3045	
8c	Interferent NH_3 with 200 nmol/mol	≤	5.0 nmol/mol (Zero)	0.160				
		≤	5.0 nmol/mol (Span)	-2.350				
8d	Interferent NO with 500 nmol/mol	≤	5.0 nmol/mol (Zero)	-0.080				
		≤	5.0 nmol/mol (Span)	1.180				
8e	Interferent NO_2 with 200 nmol/mol	≤	5.0 nmol/mol (Zero)	0.550				
		≤	5.0 nmol/mol (Span)	2.190				
8f	Interferent m-Xylene with 1 µmol/mol	≤	10 nmol/mol (Zero)	0.940				
		≤	10 nmol/mol (Span)	2.190				
9	Averaging effect	≤	7.0% of measured value	-1.200	u_{av}	-0.91	0.8364	
10	Reproducibility standard deviation under field conditions	≤	5.0% of average over 3 months	1.830	$u_{r,f}$	2.42	5.8351	
11	Long term drift at zero level	≤	4.0 nmol/mol	-1.020	$u_{d,l,z}$	-0.59	0.3468	
12	Long term drift at span level	≤	5.0% of max. of certification range	1.020	$u_{d,l,lh}$	0.78	0.6043	
18	Difference sample/calibration port	≤	1.0%	-0.140	$u_{\Delta sc}$	-0.18	0.0342	
21	Uncertainty of test gas	≤	3.0%	2.000	u_{cg}	1.32	1.7424	
					Combined standard uncertainty	u_c	7.3512	nmol/mol
					Expanded uncertainty	U	14.7024	nmol/mol
					Relative expanded uncertainty	W	11.14	%
					Maximum allowed expanded uncertainty	W_{req}	15	%

Table 36: Expanded uncertainty. Laboratory test for system 2

Measuring device:	N100				Serial-No.:		SN: 55	
Measured component:	SO2				1h-limit value:		132	nmol/mol
No.	**Performance characteristic**	**Performance criterion**		**Result**	**Partial uncertainty**		**Square of partial uncertainty**	
1	Repeatability standard deviation at zero	≤	1.0 nmol/mol	0.100	$u_{r,z}$	0.02	0.0006	
2	Repeatability standard deviation at 1h-limit value	≤	3.0 nmol/mol	0.230	$u_{r,lh}$	0.06	0.0032	
3	"lack of fit" at 1h-limit value	≤	4.0% of measured value	0.800	$u_{l,lh}$	0.61	0.3717	
4	Sensitivity coefficient of sample gas pressure at 1h-limit value	≤	2.0 nmol/mol/kPa	0.400	u_{gp}	3.25	10.5920	
5	Sensitivity coefficient of sample gas temperature at 1h-limit value	≤	1.0 nmol/mol/K	0.060	u_{gt}	0.72	0.5249	
6	Sensitivity coefficient of surrounding temperature at 1h-limit value	≤	1.0 nmol/mol/K	0.356	u_{st}	4.36	19.0123	
7	Sensitivity coefficient of electrical voltage at 1h-limit value	≤	0.30 nmol/mol/V	0.030	u_V	0.28	0.0794	
8a	Interferent H_20 with 19 mmol/mol	≤	10 nmol/mol (Zero)	0.000	u_{H2O}	-2.22	4.9445	
		≤	10 nmol/mol (Span)	-2.980				
8b	Interferent H_2S with 200 nmol/mol	≤	5.0 nmol/mol (Zero)	0.160	$u_{int,pos}$ or $u_{int,neg}$	2.35	5.5216	
		≤	5.0 nmol/mol (Span)	0.080				
8c	Interferent NH_3 with 200 nmol/mol	≤	5.0 nmol/mol (Zero)	-0.160				
		≤	5.0 nmol/mol (Span)	-2.580				
8d	Interferent NO with 500 nmol/mol	≤	5.0 nmol/mol (Zero)	0.000				
		≤	5.0 nmol/mol (Span)	-1.490				
8e	Interferent NO_2 with 200 nmol/mol	≤	5.0 nmol/mol (Zero)	0.780				
		≤	5.0 nmol/mol (Span)	1.650				
8f	Interferent m-Xylene with 1 µmol/mol	≤	10 nmol/mol (Zero)	0.860				
		≤	10 nmol/mol (Span)	1.410				
9	Averaging effect	≤	7.0% of measured value	-1.700	u_{av}	-1.30	1.6785	
18	Difference sample/calibration port	≤	1.0%	-0.280	$u_{\Delta sc}$	-0.37	0.1366	
21	Uncertainty of test gas	≤	3.0%	2.000	u_{cg}	1.32	1.7424	
					Combined standard uncertainty	u_c	6.6789	nmol/mol
					Expanded uncertainty	U	13.3578	nmol/mol
					Relative expanded uncertainty	W	10.12	%
					Maximum allowed expanded uncertainty	W_{req}	15	%

Table 37: Expanded uncertainty. Laboratory and field tests for system 2

Measuring device:	N100				Serial-No.:		SN: 55	
Measured component:	SO2				1h-limit value:		132	nmol/mol
No.	**Performance characteristic**	**Performance criterion**		**Result**	**Partial uncertainty**		**Square of partial uncertainty**	
1	Repeatability standard deviation at zero	≤	1.0 nmol/mol	0.100	$u_{r,z}$	0.02	0.0006	
2	Repeatability standard deviation at 1h-limit value	≤	3.0 nmol/mol	0.230	$u_{r,lh}$	not considered, as ur,lh = 0.05 < ur,f	-	
3	"lack of fit" at 1h-limit value	≤	4.0% of measured value	0.800	$u_{l,lh}$	0.61	0.3717	
4	Sensitivity coefficient of sample gas pressure at 1h-limit value	≤	2.0 nmol/mol/kPa	0.400	u_{gp}	3.25	10.5920	
5	Sensitivity coefficient of sample gas temperature at 1h-limit value	≤	1.0 nmol/mol/K	0.060	u_{gt}	0.72	0.5249	
6	Sensitivity coefficient of surrounding temperature at 1h-limit value	≤	1.0 nmol/mol/K	0.356	u_{st}	4.36	19.0123	
7	Sensitivity coefficient of electrical voltage at 1h-limit value	≤	0.30 nmol/mol/V	0.030	u_V	0.28	0.0794	
8a	Interferent H_20 with 19 mmol/mol	≤	10 nmol/mol (Zero)	0.000				
		≤	10 nmol/mol (Span)	-2.980	u_{H2O}	-2.22	4.9445	
8b	Interferent H_2S with 200 nmol/mol	≤	5.0 nmol/mol (Zero)	0.160				
		≤	5.0 nmol/mol (Span)	0.080	$u_{int,pos}$ or $u_{int,neg}$	2.35	5.5216	
8c	Interferent NH_3 with 200 nmol/mol	≤	5.0 nmol/mol (Zero)	-0.160				
		≤	5.0 nmol/mol (Span)	-2.580				
8d	Interferent NO with 500 nmol/mol	≤	5.0 nmol/mol (Zero)	0.000				
		≤	5.0 nmol/mol (Span)	-1.490				
8e	Interferent NO_2 with 200 nmol/mol	≤	5.0 nmol/mol (Zero)	0.780				
		≤	5.0 nmol/mol (Span)	1.650				
8f	Interferent m-Xylene with 1 µmol/mol	≤	10 nmol/mol (Zero)	0.860				
		≤	10 nmol/mol (Span)	1.410				
9	Averaging effect	≤	7.0% of measured value	-1.700	u_{av}	-1.30	1.6785	
10	Reproducibility standard deviation under field conditions	≤	5.0% of average over 3 months	1.830	$u_{r,f}$	2.42	5.8351	
11	Long term drift at zero level	≤	4.0 nmol/mol	-0.630	$u_{d,l,z}$	-0.36	0.1323	
12	Long term drift at span level	≤	5.0% of max. of certification range	0.880	$u_{d,l,lh}$	0.67	0.4498	
18	Difference sample/calibration port	≤	1.0%	-0.280	$u_{\Delta sc}$	-0.37	0.1366	
21	Uncertainty of test gas	≤	3.0%	2.000	u_{cg}	1.32	1.7424	
					Combined standard uncertainty	u_c	7.1430	nmol/mol
					Expanded uncertainty	U	14.2859	nmol/mol
					Relative expanded uncertainty	W	10.82	%
					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 14212

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

Guido Baum

Dipl.-Ing. Martin Schneider

Dipl.-Ing. Guido Baum

Cologne, 28 August 2023
EuL/21255654/C

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 14212: Ambient air - Standard method for the measurement of the concentration of sulphur dioxide by ultraviolet fluorescence, November 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 according to EN ISO/IEC 17025:2018**
Appendix 2	**Weather data during field testing**
Appendix 3	**Results of the test "Sensitivity to sample gas pressure" with the unregulated pump**
Appendix 4	**Results of the test with an alternative particulate filter**
Appendix 5	**Manual**

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

Diese Urkunde gibt den Stand zum Zeitpunkt des Ausstellungsdatums wieder. Der jeweils aktuelle Stand der gültigen und überwachten Akkreditierung ist der Datenbank akkreditierter Stellen der Deutschen Akkreditierungsstelle zu entnehmen (www.dakks.de).

Siehe Hinweise auf der Rückseite

Figure 16: Certificate of accreditation according to EN ISO/IEC 17025:2018

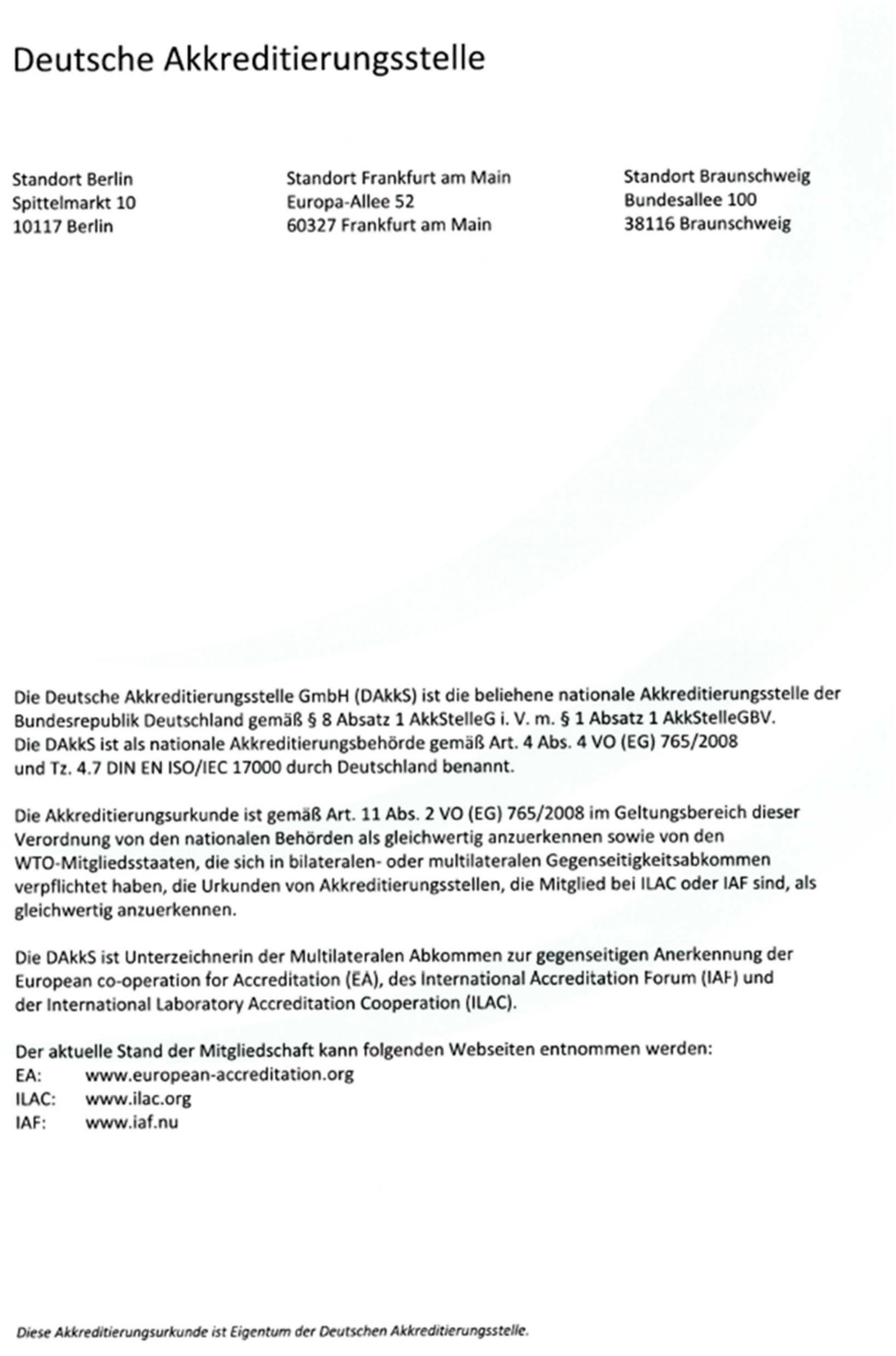


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Figure 16: Certificate of accreditation according to EN ISO/IEC 17025:2018 - page 2

Appendix 2:

Table 38: Weather data (daily averages), May 2023

May 2023	Date	Avg. Air temperature [°C]	Rel. Humidity [%] [%]	Air pressure [hPa]
15	15.05.2023	14.8	77.6	1008.3
16	16.05.2023	11.6	72.9	1014.0
17	17.05.2023	11.5	67.4	1019.6
18	18.05.2023	11.7	65.2	1020.0
19	19.05.2023	14.0	62.5	1017.6
20	20.05.2023	14.5	71.9	1014.2
21	21.05.2023	17.6	78.2	1009.4
22	22.05.2023	18.8	82.2	1008.6
23	23.05.2023	15.0	75.5	1014.1
24	24.05.2023	11.3	71.3	1017.7
25	25.05.2023	13.0	74.2	1019.9
26	26.05.2023	14.1	69.2	1021.7
27	27.05.2023	16.5	58.9	1018.5
28	28.05.2023	17.6	60.4	1013.4
29	29.05.2023	17.0	63.6	1016.0
30	30.05.2023	15.8	56.2	1018.5
31	31.05.2023	18.7	62.0	1016.7

Table 39: Weather data (daily averages), June 2023

June 2023	Date	Avg. Air temperature [°C]	Rel. Humidity [%] [%]	Air pressure [hPa]
1	01.06.2023	17.1	65.9	1014.5
2	02.06.2023	15.1	62.7	1014.1
3	03.06.2023	16.9	54.6	1013.7
4	04.06.2023	17.8	48.2	1014.2
5	05.06.2023	19.0	51.4	1013.4
6	06.06.2023	19.4	58.3	1012.7
7	07.06.2023	18.7	73.4	1012.6
8	08.06.2023	19.7	76.1	1009.5
9	09.06.2023	21.5	65.6	1007.8
10	10.06.2023	23.6	53.8	1008.4
11	11.06.2023	24.1	52.7	1009.7
12	12.06.2023	22.9	49.0	1009.1
13	13.06.2023	22.3	44.8	1007.5
14	14.06.2023	20.4	49.1	1009.8
15	15.06.2023	20.5	51.0	1012.6
16	16.06.2023	20.9	49.1	1011.9
17	17.06.2023	21.9	46.2	1009.6
18	18.06.2023	22.8	50.4	1006.6
19	19.06.2023	24.3	59.6	1006.2
20	20.06.2023	25.1	62.8	1005.5
21	21.06.2023	23.1	70.9	1010.2
22	22.06.2023	21.5	84.4	1008.9
23	23.06.2023	21.0	71.1	1015.4
24	24.06.2023	23.1	61.3	1017.9
25	25.06.2023	24.9	55.0	1012.1
26	26.06.2023	22.1	56.9	1010.8
27	27.06.2023	19.5	56.7	1014.3
28	28.06.2023	19.1	70.1	1013.1
29	29.06.2023	21.5	70.5	1009.2
30	30.06.2023	18.9	69.0	1007.6

Table 40: Weather data (daily averages), July 2023

July 2023	Date	Avg. Air temperature [°C]	Rel. Humidity [%] [%]	Air pressure [hPa]
1	01.07.2023	18.7	72.0	1001.7
2	02.07.2023	18.8	64.8	1004.8
3	03.07.2023	18.4	56.0	1006.3
4	04.07.2023	19.3	58.1	1007.2
5	05.07.2023	17.8	67.2	1005.7
6	06.07.2023	18.7	58.2	1012.2
7	07.07.2023	21.9	51.6	1013.3
8	08.07.2023	25.3	51.0	1010.8
9	09.07.2023	25.1	68.7	1012.5
10	10.07.2023	23.6	66.6	1014.7
11	11.07.2023	26.0	54.0	1007.5
12	12.07.2023	22.3	59.0	1006.3
13	13.07.2023	19.6	57.4	1011.6
14	14.07.2023	22.3	54.0	1008.6
15	15.07.2023	22.2	65.8	1002.0
16	16.07.2023	21.6	53.0	1008.3
17	17.07.2023	19.6	60.9	1013.2
18	18.07.2023	20.1	62.1	1013.2
19	19.07.2023	20.1	60.5	1008.2
20	20.07.2023	19.9	62.6	1008.7
21	21.07.2023	17.6	74.4	1006.5
22	22.07.2023	19.1	55.1	1008.2
23	23.07.2023	19.6	67.6	1003.6
24	24.07.2023	19.3	80.8	999.3
25	25.07.2023	16.2	76.1	1001.7
26	26.07.2023	16.5	73.0	1007.1
27	27.07.2023	17.2	88.2	1002.3
28	28.07.2023	19.8	90.1	1002.3
29	29.07.2023	19.1	90.7	1003.0
30	30.07.2023	18.6	73.8	1006.9
31	31.07.2023	18.5	81.6	1003.8

Table 41: Weather data (daily averages), August 2023

August 2023	Date	Avg. Air temperature [°C]	Rel. Humidity [%] [%]	Air pressure [hPa]
1	01.08.2023	17.6	83.3	996.2
2	02.08.2023	18.2	86.0	990.7
3	03.08.2023	18.1	81.2	995.1
4	04.08.2023	17.1	83.9	1007.6
5	05.08.2023	16.5	87.7	1007.1
6	06.08.2023	14.6	93.1	1001.4
7	07.08.2023	15.4	76.0	1009.7
8	08.08.2023	16.4	71.6	1009.4
9	09.08.2023	18.0	74.9	1010.5
10	10.08.2023	18.6	65.7	1015.5
11	11.08.2023	22.9	65.0	1014.0
12	12.08.2023	21.6	84.4	1011.3
13	13.08.2023	20.6	73.7	1011.5
14	14.08.2023	20.3	80.3	1009.2
15	15.08.2023	22.0	85.8	1010.1
16	16.08.2023	21.5	87.7	1013.1
17	17.08.2023	20.6	88.7	1012.2
18	18.08.2023	22.7	82.0	1009.7
19	19.08.2023	24.5	78.6	1010.1
20	20.08.2023	23.9	77.6	1015.7
21	21.08.2023	23.7	75.6	1016.2

Appendix 3:

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

Table 42: Sensitivity coefficient of the sample gas pressure with the regulated pump

	requirement	device 1		device 2	
sensitivity coeff. sample gas pressure b_{gp} [nmol/mol/kPa]	≤ 2,0	0.32	✓	0.30	✓

Table 43: Individual results of the sensitivity to changes in sample gas pressure with the regulated pump

time	pressure [kPa]	concentration	device 1 [nmol/mol]	device 2 [nmol/mol]
09:25:00	80	281.00	294.17	291.93
09:26:00	80	281.00	294.67	291.71
09:27:00	80	281.00	294.89	291.47
average C_{P1}			294.58	291.71
09:42:00	110	281.00	284.97	282.71
09:43:00	110	281.00	284.72	282.94
09:44:00	110	281.00	284.96	282.71
average C_{P2}			284.88	282.78

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 44: Data from the test gas application with alternative particle filter

Zero Concentration			
		Device 1	Device 2
Date	Time	[nmol/mol]	[nmol/mol]
21.08.2023	08:53:00	0.23	0.00
	08:54:00	0.23	0.23
	08:55:00	0.23	0.23
	08:56:00	0.23	0.23
	08:57:00	0.23	0.23
	aver. $c_{z,1}$	**0.23**	**0.19**
21.08.2023	09:51:00	0.00	0.05
	09:52:00	0.00	0.23
	09:53:00	0.23	0.23
	09:54:00	0.23	0.00
	09:55:00	0.23	0.23
	aver. $c_{z,1}$	**0.14**	**0.15**

C_t-Concentration			
		Device 1	Device 2
Date	Time	[nmol/mol]	[nmol/mol]
21.08.2023	09:30:00	284.35	284.12
	09:31:00	284.59	284.12
	09:32:00	284.59	284.12
	09:33:00	284.82	284.12
	09:34:00	284.59	284.12
	aver. $c_{s,1}$	**284.59**	**284.12**
21.08.2023	10:12:00	283.59	284.51
	10:13:00	283.59	284.51
	10:14:00	283.92	284.53
	10:15:00	283.77	284.94
	10:16:00	283.77	284.94
	aver. $c_{s,1}$	**283.73**	**284.69**

Appendix 5:

Manual