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**TÜV IMMISSIONSSCHUTZ
UND ENERGIESYSTEME GMBH**

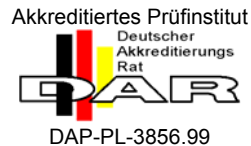
Translation of the report on the suitability test of
the ambient air measuring system Analyser
Model 42i of the company Thermo Electron Corporation for the components NO, NO₂ and NO_x

TÜV-Report-No.: 936/21203248/C1
Cologne, January 5, 2006

**TÜV Immissionsschutz und Energiesysteme GmbH holds an accreditation under the terms of
DIN EN ISO/IEC 17025 and DIN EN ISO 9002 in the following field of work:**

- Determination of emissions and immissions of air pollutants and odorants;
- Verification of the correct installation and the function as well as the calibration of continuous operating emission measuring systems including systems for data evaluation and remote monitoring of emissions;
- Suitability testing of measuring systems for continuous monitoring of emissions and immissions as well as for electronic systems for data evaluation and remote monitoring of emissions

The accreditation is valid up to 04-12-2010.
DAR-Registration number: DAP-PL-3856.99.



Translation of the report on the suitability test of the ambient air measuring system Analyser Model 42i of the company Thermo Electron Corporation for the components NO, NO2 and NOx

Measuring system tested:	Analyser Model 42i
Manufacturer of the Instrument:	Thermo Electron Corporation 27 Forge Parkway Franklin, MA 02038 USA Fraunauracher Straße 96 91056 Erlangen Germany
Time period of testing:	February 2005 to September 2005
Date of report:	January 5, 2006
Number of report:	936/21203248/C1
Scope of report:	In total 553 pages Appendix from page 109 manual from page 135 with 418 pages

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1 Summary and proposal for declaration of suitability

1.1 Abstract

The report 936/21203248/C1 at hand is a revised version of the suitability test report 936/21203248/C of 05.01.2006. The revision was necessary in order to document in the report the gain of knowledge since the implementation of the standard EN 14211.

By order of the Thermo Electron Corporation the TÜV Immissionsschutz und Energiesysteme GmbH has accomplished the suitability test of the measuring system Analyser Model 42i for the component NO, NO₂ und NO_x.

The testing was performed in accordance to the following guidelines and requirements:

- VDI 4202 Part 1: Minimum requirements for suitability tests of automated ambient air quality measuring systems; Point-related measurement methods of gaseous and particulate pollutants, from June 2002
- VDI 4203 Part 3: Testing of automated measuring systems; Test procedures for point-related ambient air quality measuring systems of gaseous and particulate pollutants, from August 2004
- EN 14211 Ambient air quality - Standard method for the measurement of the concentration of nitrogen dioxide and nitrogen monoxide by chemiluminescence, from July 2005

The measuring system tested operates using the chemiluminescence-principle.

The test work took place in the laboratory and during a field test with a duration of three months as an endurance test. The tested measuring ranges are:

Component		Measuring range		
Nitrogen monoxide	NO	1200	µg/m ³	EN 14211
Nitrogen dioxide	NO ₂	400	µg/m ³	VDI 4202 Bl. 1
Nitrogen dioxide	NO ₂	500	µg/m ³	EN 14211

The minimum requirements and the requirements of EN 14211 have been fulfilled in the suitability test.

Therefore the TÜV Immissionsschutz und Energiesysteme GmbH proposes the publication as a suitability-tested measuring system for continuous monitoring of NO, NO₂ and NO_x in the ambient air.

1.2 Proposal for declaration of suitability

Due to the positive achieved results, the following recommendation for declaration of suitability as suitability-tested measuring system is given:

- | | | | | |
|---------------|-----------------------------------------------------|---|-------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------|
| 1.2.1 | Measurement task | : | Measuring system for determination of the NO, NO ₂ und NO _x concentrations in the ambient air | |
| 1.2.2 | Name of device | : | Analyser Model 42i | |
| 1.2.3 | Measured components | : | NO, NO ₂ , and NO _x | |
| 1.2.4 | Manufacturer | : | Thermo Electron Corporation
27 Forge Parkway
Franklin, MA 02038
USA

Frauenauracher Straße 96
91056 Erlangen
Germany | |
| 1.2.5 | Scope of suitability | : | For continuous ambient air measurement of NO, NO ₂ and NO _x in stationary operation | |
| 1.2.6 | Measuring ranges during the suitability test | : | Nitrogen dioxide | 0 to 400 µg/m ³ |
| | | | Nitrogen dioxide | 0 to 500 µg/m ³ |
| | | | Nitrogen monoxide | 0 to 1200 µg/m ³ |
| 1.2.7 | Software version | : | V 01.03.00.094 | |
| 1.2.8 | Restrictions | : | | |
| 1.2.9 | Remarks | : | | |
| 1.2.10 | Test institute | : | TÜV Immissionsschutz und Energiesysteme GmbH, Köln
TÜV Rheinland Group
Responsible auditor: Guido Baum | |
| 1.2.11 | Test report | : | 936/21203248/C1 of January 5, 2006 | |

1.3 Summary of test results

Minimum requirement	Requirement	Test results	ful-filled?	Page	
4	Requirements on the instrument design				
4.1	General requirements				
4.1.1	Measured value display	Must exist.	A measured value display exists.	yes	23
4.1.2	Easy maintenance	Maintenance of the measuring systems should be possible without larger effort, if possible from outside.	The Maintenance of the measuring systems is possible without higher complexity.	yes	24
4.1.3	Functional check	If the operation ort eh functional check of the measuring system require particular instruments, they shall be considered as part of the measuring system and shall be applied in the corresponding sub-tests and included in the assessment. Test gas units included in the measuring system shall indicate their operational readiness to the measuring system by a status signal and shall provide direct as well as remote control via the measuring system. The uncertainty of the test gas shall not exceed 1 % of reference value B ₂ within three month.	not applicable	not applicable	25
4.1.4	Set-up times and warm-up times	The instruction manual must include information to this topic.	The set-up time amounts to 90 minutes. The warm-up time is specified with 90 minutes in the manual and in the tests performed a period of 90 minutes was found.	yes	26
4.1.5	Instrument design	The instruction manual must include information to this topic.	In the manual the instrument design and the basic conditions are described in details.	yes	27
4.1.6	Unintended adjustment	Must be secure against unintended adjustment	The measuring equipment is protected against unauthorized adjusting by means of passwords.	yes	29
4.1.7	Data output	Must be provided digitally and/or analogue.	Measurement signals and operating states are recognized by downstream evaluating-systems correctly. All measurement signals can be provided in digital form and in analogue mode.	yes	30

Minimum requirement	Requirement	Test results	ful-filled?	Page
4.2 Requirements for the mobile Application	Permanent operational standby mode must be secure. The requirements of the stationary application shall comply with the requirements for the mobile application.	An evaluation is dropped, because this possible application was not tested.	not applicable	31
5. Performance requirements				
5.1 General				
5.2 General requirements on measuring systems				
5.2.1 Measuring range	The upper limit of the range shall be higher than B ₂ .	The measuring ranges can be chosen optional according to the requirements.	yes	32
5.2.2 Negative output signals	Negative output signals or measured values may not be suppressed (life zero).	The position of the zero point of the measuring signal is so far away from electrical zero, that the permissible zero point drift can surely be registered.	yes	33
5.2.3 Analytical function	The relationship between the output signal and the value of the air quality characteristic shall be represented by the analytical function and determined by regression analysis	The measuring equipment allows the formation of one-hour mean values.	yes	34
5.2.4 Linearity	Deviations of the group averages of measured values about the calibration function are smaller than 5 % of B ₁ in the range of zero to B ₁ , and smaller than 1 % of B ₂ in the range of zero to B ₂ .	The two analysers meet the requirements of the guidelines.	yes	36
5.2.5 Detection limit	Maximum B ₀ .	The detection limit is within the minimum requirements.	yes	43
5.2.6 Response time	Maximum 5 % of the response time (180 seconds).	The maximal permissible response time of 180 seconds is fallen below clearly..	yes	48
5.2.7 Dependence of the zero point on ambient temperature	The measured value at zero shall not exceed the reference value B ₀ if ambient temperature is changed by 15 K in the range of +5 °C to +20 °C or 20 K in the range of +20 °C und +40 °C.	The change of the zero point is at all ambient temperatures within the limit of the minimum requirement.	yes	51
5.2.8 Dependence of the measured value on ambient temperature	The temperature dependence of the measured value in the range of reference value B ₁ shall not exceed 5 % of the measured value if ambient temperature is changed by 15 K in the range of +5 °C to +20 °C or 20 K in the range of +20 °C to +40 °C.	The change of the span point is at all ambient temperatures within the limit of the minimum requirement.	yes	55

Minimum requirement	Requirement	Test results	ful-filled?	Page
5.2.9 Drift of zero point	In 24 hours and in the maintenance interval maximum B ₀ .	The zero point drifts meets the minimum requirements.	yes	59
5.2.10 Drift of measured value	In 24 hours and in the maintenance interval maximum 5 % of B ₁ .	The span point drift meets the minimum requirements .	yes	63
5.2.11 Cross-sensitivities	At the zero point maximum B ₀ and at the B ₂ level maximum 3 % of B ₂ .	The cross-sensitivities of the measuring systems fulfill the minimum requirements.	yes	67
5.2.12 Reproducibility RD	RD ≥ 10 based on B ₁ .	The minimum value of 10 for the repeatability required by the VDI 4202 part 1 is exceeded clearly. Thus the minimum standards are kept.	yes	70
5.2.13 Hourly averages	Creation must be possible.	The measuring equipment allows the formation of one-hour mean values.	yes	75
5.2.14 Mains voltage and frequency	Variation of the measured value at B ₁ maximum B ₀ in the voltage interval (230 +15/-20)V and variation of the measured value for mobile application maximum B ₀ in the frequency interval of (50 ± 2) Hz.	The measuring system fulfils the minimum requirements regarding the variations of the mains voltage.	yes	76
5.2.15 Failure in the mains voltage	In case of malfunction of the measuring system or failure in the mains voltage, uncontrolled emission of operating and calibrating gas shall be avoided. The instrument 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.	The minimum requirements are kept during a power breakdown. The operability of the analyser is safeguarded and calibrating gas does not exhaust.	yes	81
5.2.16 Operating states	Measuring systems shall be able to telemetrically transmit important operating states by status signals.	The essential operating states are controllable via telemetric status signals.	yes	82
5.2.17 Switch-over	Switch-over between measurement and functional check and/or calibration shall be possible telemetrically control or manual intervention.	The switch-over between the modes of operation is manual and telemetric possible.	yes	83
5.2.18 Availability	Minimum 90 %.	The availability is higher than 90 %, so that the minimum requirement is fulfilled .	yes	84
5.2.19 Efficiency of the converter	Minimum 95 %.	The efficiency of the converter is for both analysers higher than the required 95 %.	yes	86

Minimum requirement	Requirement	Test results	ful-filled?	Page
5.2.20 Maintenance interval	If possible 28 days, minimum 14 days.	The minimum requirements are fulfilled. The maintenance value is one month.	yes	88
5.2.21 Overall uncertainty	Compliance with the requirements for the data quality.	The measuring system falls below the required expanded uncertainty of 15 % clearly by a result of 8.59 %.	yes	90
5.3 Requirements on measuring systems for particulate air pollutants				
5.4 Requirements on multiple-component measuring systems	Multiple-component measuring systems shall comply with the requirements set for each component, also in case of simultaneous operation of all measuring channels.	Not applicable.	not applicable	93

2 Terms of reference

2.1 Kind of testing

On behalf of the company Thermo Electron Corporation, TÜV Immissionsschutz und Energiesysteme GmbH performed a complete suitability test for the measuring system Analyser Model 42i. The test followed the guidelines for the minimum requirements according to VDI 4202 and EN 14211.

2.2 Objective

The objective of the test was to show, that the measuring system fulfils the German minimum requirements for the VDI 4202 part 1 and the European minimum requirements for the EN 14211. Therefore the measuring system was tested in the following measuring ranges:

Table 1: Tested components and measuring ranges

Component		Measuring range		
Nitrogen monoxide	NO	1200	µg/m ³	EN 14211
Nitrogen dioxide	NO ₂	400	µg/m ³	VDI 4202 part. 1
Nitrogen dioxide	NO ₂	500	µg/m ³	EN 14211

3 Description of the tested system

3.1 Measuring principle

The Model 42i operates on the principle that nitric oxide (NO) and ozone (O₃) react to produce a characteristic luminescence with an intensity linearly proportional to the NO concentration.

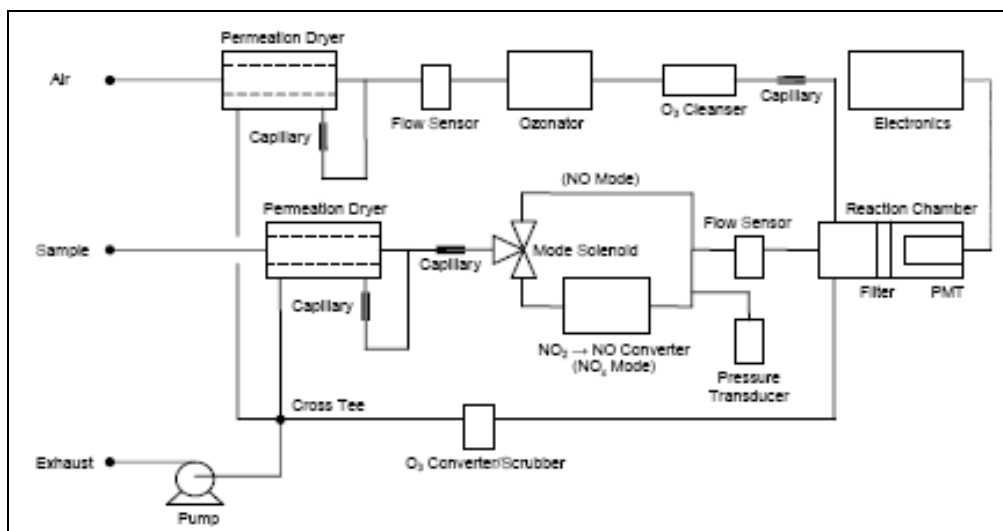


Figure 1: Model 42i – Scheme of the measuring principle

The ambient air sample flows through an particulate filter, an permeation dryer and an flow controller over an converter to the reaction chamber. The converter changes the in the nitrogen dioxide to nitric oxide at a temperature of 325 °C. The necessary ozone is generated out of dry air in an ozone generator with UV radiation. In the reaction chamber is an to the ozone concentration equivalent NO concentration oxidated to NO₂. This reaction is named gas-phase-titration. A photomultiplier tube (PMT) housed in a thermoelectric cooler detects the luminescence generated during this reaction. After that the Model 42i calculates the NO-, NO₂- und NO_x-concentration.

3.2 Extent and set-up of the measuring system

In the following graphics and explanations are the most important parts of the analyser described.

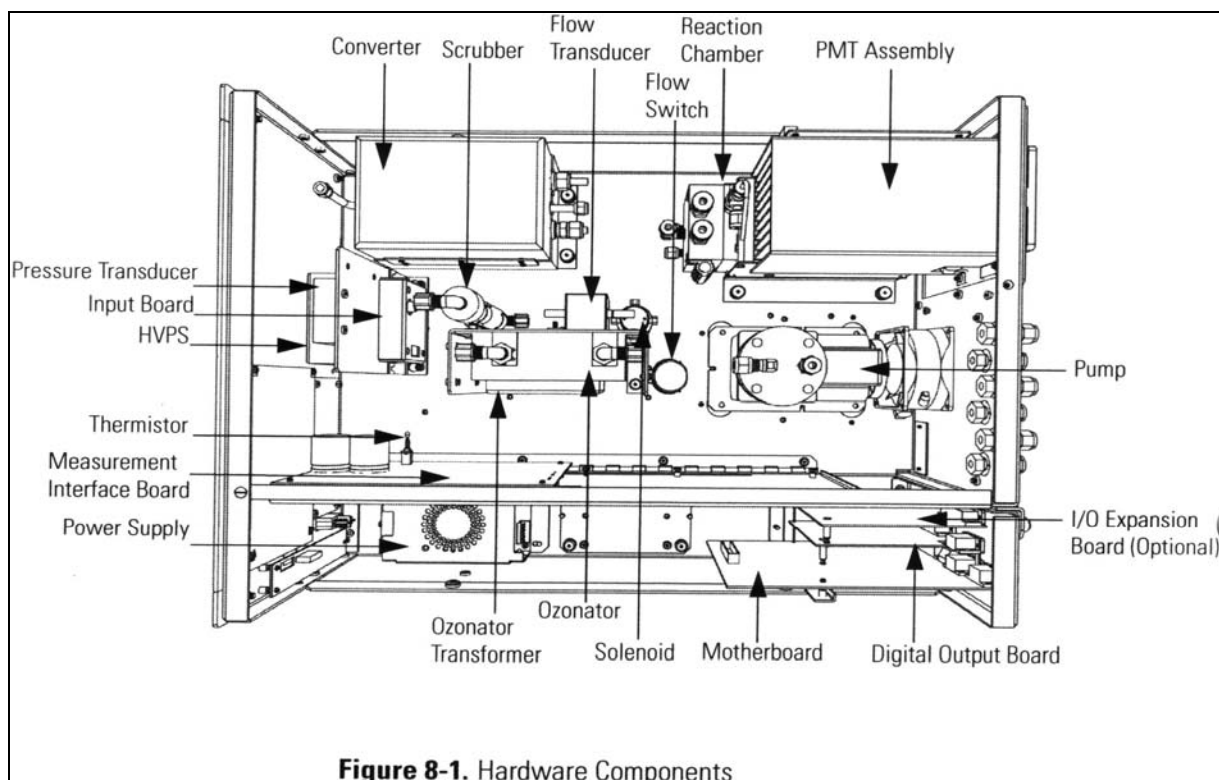


Figure 2: Hardware of the analyser model 42i

NO ₂ -NO-Converter:	The NO ₂ -to-NO converter heats molybdenum to approximately 325 °C (EPA designated) or stainless steel to 625 °C in order to convert and detect NO ₂ . The converter consists of an insulated housing, heater, replaceable cartridge and a type K thermocouple sensor.
Mode Solenoid:	The mode solenoid valve switches analyser operation between the NO mode and NO _x Mode. It routes the ambient air sample either through the reaction chamber (NO mode) or through the NO ₂ -to-NO converter and then to the reaction chamber1.
Reaction Chamber:	The reaction chamber is where the sample reacts with ozone and produces excited NO ₂ that gives off a photon of energy when it decays. It is heated to 50 °C.
Optical Filter:	The optical filter housed in the reaction chamber limits the spectral region viewed by the detector.
Ozonator:	The Ozonator generates the necessary ozone concentration required for the chemiluminescent reaction. The ozone reacts with the NO in the ambient air sample to produce the electronically excited NO ₂ molecules.
Photomultiplier Tube:	The Photomultiplier tube (PMT) provides the infrared sensitivity required to detect the NO ₂ luminescence resulting from the reaction of the ozone with the ambient air sample.

4 Test Program

4.1 Laboratory test

The lab test has been done with two identical analysers of the type Analyser Model 42i with the serial numbers 42i-PTR-01 and 42i-PTR-2. According to the guidelines the following test program arise for the laboratory test:

- Inspection of the general analyser functions
- Determination of the device characteristic with test gases,
- Determination of the cross-sensitivity of the measuring system against accompanying substances in the ambient air,
- Check of the stability of the zero-point and reference-point in the permissible ambient temperature range,
- Determination of the effect of changes in mains voltage on the measured signal,
- Response time
- Detection limit

4.2 Field test

The field test took place at a large parking lot in cologne. The analysers have been installed during the field test in an air conditioned container. Figure 3 shows the installed measuring systems.

The following analysers have been tested:

Unit 1: 42i – PTR - 01

Unit 2: 42i – PTR - 02



Figure 3: Front shoot of the analysers in the measuring container

The endurance test took place from 28.04.2005 to 14.09.2005. The analysers had during this period the following configuration:

Component		Measuring range	
Nitrogen monoxide	NO	1200	µg/m ³
Nitrogen Dioxide	NO ₂	400	µg/m ³

For the field test the following test program was established:

- Functional check of the general device functions,
- Functional check of the measuring systems at the beginning and at the end of the field test,
- Determination of the detection limit,
- Determination of reproducibility R_D ,
- Determination of the drift behaviour at zero-point and reference point,
- Determination of maintenance interval,
- Determination of availability.

5 Reference method

5.1 Component: NO₂

The NO₂ test gas has been produced by means of an permeation oven of the company MCZ during the tests in the laboratory and the field. For the validation of the produced NO₂ concentration and for the determination of the permeation rate of the used permeation tube the weight difference of the tube is checked in specific periods of time. During this times the permeation tube was stored under defined climatic circumstances

These gravimetric determination of the permeation rate has been done continuously during the complete suitability test.

In addition different measurements with the Saltzman-method according to VDI 2453 part 1 have been done at different concentration levels. Each adjusted concentration of the permeation system has been compared with the measured concentration of the analysers and the Saltzman method.

5.2 Component: NO

For the NO test gas offerings a gas out of a cylinder with the cylinder number 10305 from the manufacturer Air Liquide has been used. The uncertainty of the test gas was 2 %. The concentration of the test gas has been determinated by the reference method according to VDI 2456.

The different concentrations have been diluted by means of mass flow controllers by use of synthetic air as dilution gas.

5.3 Assembly in the field

The set-up of the testing arrangement in the laboratory was matched to the requirements of the specific tests and was duplicated in a simplified manner in the field test site (see Figure 4).



Figure 4: Test gas application by permeation system and computer for controlling

6 Test results

6.1 4.1.1 Measured value display

The measuring system shall be fitted with a measured value display.

6.2 Equipment

Camera.

6.3 Testing

The equipment of the measuring system has been tested visually for the presence of the measured value display.

6.4 Evaluation

The measuring system has a measured value display, which indicates in addition to the measured value important system parameters.

6.5 Assessment

A measured value display exists.

Minimum requirement fulfilled? yes

6.6 Documentation

At the front view of the analyser in Figure 5 the display of the measured value can be seen.



Figure 5: Front-view of the analyser Thermo 42i

6.1 4.1.2 Easy maintenance

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

6.2 Equipment

Common tools.

6.3 Testing

The maintenance operations for the analysers have been done like described in the manual. For the realisation have only common tools been used.

6.4 Evaluation

The maintenance of the measuring systems is trouble-free possible by use of common tools.

6.5 Assessment

The Maintenance of the measuring systems is possible without higher complexity.

Minimum requirement fulfilled? yes

6.6 Documentation

Here not essential.

6.1 4.1.3 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 shall be applied in the corresponding sub-tests and included in the assessment.

Test gas units included in the measuring system shall indicate their operational readiness to the measuring system by a status signal and shall provide direct as well as remote control via the measuring system.

The uncertainty of the test gas shall not exceed 1 % of reference value B_2 within three month.

6.2 Equipment

not applicable

6.3 Testing

The measuring system can be ordered with a functional check unit. This unit was not part of the suitability test. The daily checks with test gases for zero- and reference point have been done with an external mass-flow-controller station for the analysers.

6.4 Evaluation

not applicable

6.5 Assessment

not applicable

Minimum requirement fulfilled? not applicable

6.6 Documentation

Here not essential.

6.1 4.1.4 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

Clock, zero- and test gases .

6.3 Testing

The set-up time has been verified during the assembly in the lab and in the field on the basis of the data in the manual. The warm-up time has been defined by giving up zero and test gases after turning the analysers on.

6.4 Evaluation

For the set-up time there is no declaration in the manual. It depends on the circumstances at the mounting place and consists of the time for connecting the power supply, the gas tubes and the data logging system. Experimentally, for the set up time a period of 90 min has been defined.

The warm-up time is specified in the manual with 90 min. In our tests the measuring system needed latest 90 minutes to measure stabile values. This period of time is based on a activation of the analysers after a longer duration of shutdown, so that it was secure, that the analysers were totally un-tempered before the restart. Other tests in which the analysers have been switched off for a shorter time resulted in a shorter warm up time of about 15 to 30 minutes.

The manufacturer gives for the installation the remark, that a basic calibration should been done after 24 hours warm-up time at each location of installation.

6.5 Assessment

The set-up time amounts to 90 minutes. The warm-up time is specified with 90 minutes in the manual and in the tests performed a period of 90 minutes was found.

Minimum requirement fulfilled? yes

6.6 Documentation

Here not essential.

6.1 4.1.5 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.*

6.2 Equipment

The power consumption has been detected by using the test instrument Metraster 5 from the company Gossen Metrawatt.

6.3 Testing

The content of the manual has been checked regarding to the instrument design. The declaration of the power consumption of the analysers has been checked in a regular measuring operation.

6.4 Evaluation

The documentation in the manual includes all information for the instrument design. The essential data are given in Table 2.

Table 2: Data of the analyser Thermo 42i

Instrument shape	built-in type
Mounting position	horizontal
Sample flow rate	0,6-0,8 liters/min
Operating temperature	15-35 °C
Power requirements	100 VAC 50/60 Hz 115 VAC 50/60 Hz 220-240 VAC 50/60 Hz 300 Watts
Dimensions (H x B x T)	16.75`` x 8.62`` x 23`` (42.5 cm x 21.9 cm x 58.4 cm)
Weight	about 55 lbs. (corresponds to 25 kg)
Analog outputs	6 voltage outputs; 0-100 mV, 1, 5, 10 V (user selectable), possible 5% of full scale over/under range, 12 bit resolution, user selectable for measurement input
Digital outputs	16 digital outputs, user select programmable, TTL-Level (HIGH)
Digital inputs	16 digital inputs, user select programmable, TTL-Level (HIGH)
Serial pots	1 RS-232 or RS-485 with two connectors, baud rate 1200-115200, data bits, parity, and stop bits, protocols: C-Link, MODBUS and Streaming-Data (all user selectable)
Ethernet connection	RJ45 connector for 10 Mbs Ethernet-connection, static or dynamic TCP/IP addressing
Software version	V 01.03.00.094

The determination of the power consumption has been done in a period of 24 h in regular measuring operation during the field test. At a supply voltage of 230 V the results displayed in Table 3 have been found.

Table 3: Test of the power consumption during regular operation

	Current consumption [A]	Power consumption [W]
Unit 1	1.06	244
Unit 2	1.11	255

6.5 Assessment

In the manual the instrument design and the basic conditions are described in details. Regarding the power consumption, the detected values fall below the specifications listed in the manual.

Minimum requirement fulfilled? yes

6.6 Documentation

Here not essential.

6.1 4.1.6 Unintended adjustment

It shall be possible to secure the adjustment of the measuring system against illicit or unintended adjustment during operation.

6.2 Equipment

Special checking facilities are not necessary.

6.3 Testing

The options to avoid an unintended or illicit adjustment of the settings of the measuring system were activated. Then it was tested whether an unauthorized or unintentional change is possible.

6.4 Evaluation

The menu areas in which a change of analyser parameters is possible, can be safeguarded by means of a password.

6.5 Assessment

The measuring equipment is protected against unauthorized adjusting by means of passwords.

Minimum requirement fulfilled? yes

6.6 Documentation

Here not essential.

6.1 4.1.7 Data output

The output signals shall be provided digitally (e. g. RS 232) and/or as analogue signals (e. g. 4 mA to 20 mA).

6.2 Equipment

Evaluating-system, Data logger and multimeter.

6.3 Testing

The operating status and the measurement signals were recorded by connection of the measuring instruments tested to the evaluating-system.

6.4 Evaluation

The measuring equipment has a great number at analogous and digital options for the connection of data loggers. Furthermore the digital variants can be adapted in particular to the individual requirements of the ambient air quality measuring network operator.

The measuring equipment has analogue outputs that can be chosen in the ranges 0-100 mV, 1, 5, and 10V. The analogue output of 0 to 10 V was mainly employed for the suitability test.

The measuring equipment has analogous status outputs for all important device functions as failures, calibrating-cycles, measuring range changeover and diagnostic modes. The recording of the measuring data was made during the aptitude test by means of analogous voltage signals, however, the possibility to provide the measurement signals as a current signal through a spare-part (option) exists. Also a digital data transfer is possible.

6.5 Assessment

Measurement signals and operating states are recognized by downstream evaluating-systems correctly. All measurement signals can be provided in digital form and in analogue mode.

Minimum requirement fulfilled? yes

6.6 Documentation

Here not essential.

6.1 4.2 Requirements for the mobile Application

Measuring systems for mobile application shall also comply with the requirements on measuring systems for stationary application in the case of mobile application. The measuring system shall be in a permanent operational stand-by mode during mobile application, e.g. measurements in running traffic, time-limited measurements at different locations or measurement on aircraft.

6.2 Equipment

Measuring vehicle.

6.3 Testing

The suitability of the measuring equipment for a mobile application (in running vehicles, airplanes etc.) was not tested. However, the measuring equipment can be used without problems for temporary measurements at different places.

6.4 Evaluation

The measuring equipment can be used without problems for temporary measurements at different places. The transportation of the measuring equipment was not tested explicitly. Therefore the usual protective measures are to be planned during the transportation against vibrations. Furthermore the set-up and warm-up times are to be considered.

6.5 Assessment

An evaluation is dropped, because this possible application was not tested.

Minimum requirement fulfilled? not applicable

6.6 Documentation

Here not essential.

6.1 5.2.1 Measuring range

The upper limit of measurement of the systems shall be greater or equal to reference value B_2 .

EN 14211: Certifying-range NO₂ : 0 - 500 µg/m³ and for NO : 0 - 1200 µg/m³.

6.2 Equipment

The measuring system to be tested.

6.3 Testing

It was tested whether the measuring range of the measuring system can be tuned freely and at least the required values are reached.

6.4 Evaluation

The measuring ranges can be chosen between 0 and 100 ppm freely. The smallest selectable range is 0 to 50 ppb. It is possible, to indicate the measurement result on the display in different units (for example [ppb], [µg/m³]). In addition to the free selectable ranges, there are a couple of fix ranges in the software of the analyser pre-configured.

6.5 Assessment

The measuring ranges can be chosen optional according to the requirements. Also the measuring range requirements are kept according to EN 14211.

Minimum requirement fulfilled? yes

6.6 Documentation

Here not essential.

6.1 5.2.2 Negative output signals

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

6.2 Equipment

Zero- and test-gas in suitable concentration, multimeter.

6.3 Testing

Through the zero point calibration with a specific NO/NO₂ concentration the zero point of the measuring system was displaced so far, that applying up zero gas negative measurement signals were indicated. At the reference point the display range was determined by application of NO/NO₂ concentrations above the full range.

6.4 Evaluation

From the experiments the following output variations at a configured analogue output range of 0 to 10 volt resulted:

Table 4: Overview of the life zero

	Minimum display field	Maximum display field
NO channel		
Unit 1	-0.6 Volt	11.6 Volt
Unit 2	-0.61 Volt	11.59 Volt
NO ₂ channel		
Unit 1	-0.58 Volt	11.58 Volt
Unit 2	-0.6 Volt	11.59 Volt
NO _x channel		
Unit 1	-0.62 Volt	11.61 Volt
Unit 2	-0.61 Volt	11.6 Volt

6.5 Assessment

The position of the zero point of the measuring signal is so far away from electrical zero, that the permissible zero point drift can surely be registered.

Minimum requirement fulfilled? yes

6.6 Documentation

Here not essential.

6.1 5.2.3 Analytical function

The relationship between the output signal and the value of the air quality characteristic shall be represented by the analytical function and determined by regression analysis.

6.2 Equipment

For the examination different nitrogen dioxide concentrations were generated by means of a permeation oven type MCZ CGM 2000. The oven operates with synthetic air out of cylinders.

6.3 Testing

The examination was made by application of graded NO₂ concentrations to the measuring system to be tested by means of a permeation system.

6.4 Evaluation

The slope and the intercept of an axis of the calibrating-function

$$Y = m \cdot x + b$$

were determined through linear regression and subsequently are given in Table 5 and Table 6 for the five calibrating-cycles together with the coefficients of correlation.

Table 5: Individual results of the 5 series of experiments for the determination of the calibrating-function for NO₂

Unit 1

Number	1	2	3	4	5
Slope m [(µg/m³)/(µg/m³)]	0.9931	0.9962	0.9962	0.9938	0.9986
Intercept of the axis b [µg/m³]	-0.2356	0.1425	-0.82	0.9483	0.1408
Correlation coefficient	0.999	0.999	1	0.999	1

Unit 2

Number	1	2	3	4	5
Slope m [(µg/m³)/(µg/m³)]	1.0008	1.0027	1.0006	0.9993	1.0048
Intercept of the axis b [µg/m³]	1.6035	0.9481	0.7319	1.2003	0.0528
Correlation coefficient	0.999	1	0.999	1	1

The analytical function was determined through conversion of the calibrating-function and reads as follows:

$$X = 1/m \cdot y - b/m$$

In the following table the values for the slopes and the intercepts of an axis for the analytical functions are given.

Table 6: Individual results of the 5 series of experiments for the determination of the analytical function for NO₂

Unit 1

Number	1	2	3	4	5
Slope 1/m [(µg/m³)/(µg/m³)]	1.0069	1.0038	1.0038	1.0062	1.0014
Intercept of the axis b/m [µg/m³]	-0.2372	0.1430	-0.8231	0.9542	0.1410

Unit 2

Number	1	2	3	4	5
Slope 1/m [(µg/m³)/(µg/m³)]	0.9992	0.9973	0.9994	1.0007	0.9952
Intercept of the axis b/m [µg/m³]	1.6022	0.9455	0.7315	1.2011	0.0525

6.5 Assessment

The relations between output signal and measurement variable are sufficiently representable by means of the analytical function and were determined through regression analysis.

Minimum requirement fulfilled? yes

6.6 Documentation

The single values are given in Table 54 to Table 58 in the appendix.

6.1 5.2.4 Linearity

Reliable linearity is given, if deviations of the group averages of measured values about the calibration function are smaller than 5 % of B_1 in the range of zero to B_1 , and smaller than 1 % of B_2 in the range of zero to B_2 .

EN 14211; 8.4.6: „Lack of fit“ for the component NO ≤ 4.0 % of the measured value at the reference point

6.2 Equipment

For the examination different nitrogen dioxide concentrations were generated by means of a permeation oven type CGM 2000. The oven operates with synthetic air out of cylinders.

For the component NO test gases like described in chapter 5.2 were used.

6.3 Testing

The examination was made by application of graded nitrogen dioxide concentrations to the measuring system to be tested by means of a permeation system analogously to the examination of the analytical function. The results were evaluated according to the rules of the linearity check.

The NO test gas concentrations were generated by an mass flow controller.

The guideline VDI 4203 part 3 as well as the EN 14211 demands for this examination for the application of test gases at 6 different, uniformly distributed point in the respective measuring ranges. In order to meet the criteria of both guidelines, the number of the measurement points was expanded, so that for the measuring range of 0 - 400 $\mu\text{g}/\text{m}^3$ as well as for the range 0- 500 $\mu\text{g}/\text{m}^3$ a sufficient number of measured values could be recorded.

6.4 Evaluation

For each individual concentration level, the mean value was determined about the five series of measurements. The deviation of the group mean values to the target values from the analysis function was determined and compared with the minimum requirements.

Thus for the component NO₂ a maximum deviation for values between zero and B_1 of -0.7 $\mu\text{g}/\text{m}^3$ respectively 0.9 $\mu\text{g}/\text{m}^3$ and a maximum deviation for values between zero and B_2 of -3.0 $\mu\text{g}/\text{m}^3$ respectively 2.4 $\mu\text{g}/\text{m}^3$ were derived. The detailed results of the investigations can be found in Table 7 and Table 8.

Table 7: *Linearity NO₂ Thermo 42i from group mean values, device 1*

Test gas value	Measured value	Deviation	Allowed deviation according to VDI 4202
[µg/m³]	[µg/m³]	[µg/m³]	[µg/m³]
0.0	0.62	0.6	3.0
45.0	44.32	-0.7	3.0
90.0	88.46	-1.5	4.0
125.0	123.46	-1.5	4.0
150.0	150.72	0.7	4.0
185.0	185.48	0.5	4.0
225.0	223.64	-1.4	4.0
265.0	264.8	-0.2	4.0
310.0	308	-2.0	4.0
350.0	349	-1.0	4.0
400.0	397	-3.0	4.0
500.0	498	-2.0	4.0

Table 8: *Linearity NO₂ Thermo 42i from group mean values, device 2*

Test gas value	Measured value	Deviation	Allowed deviation according to VDI 4202
[µg/m³]	[µg/m³]	[µg/m³]	[µg/m³]
0.0	0.8	0.8	3.0
45.0	45.9	0.9	3.0
90.0	91.2	1.2	4.0
125.0	125.2	0.2	4.0
150.0	151.8	1.8	4.0
185.0	187.0	2.0	4.0
225.0	225.4	0.4	4.0
265.0	266.8	1.8	4.0
310.0	311.6	1.6	4.0
350.0	352.4	2.4	4.0
400.0	400.4	0.4	4.0
500.0	502.0	2.0	4.0

The in the EN 14211 required maximum deviation between test gas value and measured value is 5 ppb at the zero point and 4 % of the measured value at the other test points for the component NO. The average of the test points shows the following result.

Table 9: Linearity NO Thermo 42i from group mean values, device 1

Test gas value	Measured value	Deviation	Allowed deviation according to EN 14211	Deviation
[µg/m ³]	[µg/m ³]	[µg/m ³]	[µg/m ³]	[% of measured value]
0.0	0.3	0.3	5.0	---
200.0	200.2	0.2	8.0	0.1
400.0	402.8	2.8	16.0	0.7
600.0	603.6	3.6	24.0	0.6
800.0	802.0	2.0	32.0	0.3
1000.0	1006.2	6.2	40.0	0.6
1200.0	1209.4	9.4	48.0	0.8

Table 10: Linearity NO Thermo 42i from group mean values, device 2

Test gas value	Measured value	Deviation	Allowed deviation according to EN 14211	Deviation
[µg/m ³]	[µg/m ³]	[µg/m ³]	[µg/m ³]	[% of measured value]
0.0	0.6	0.6	5.0	---
200.0	202.6	2.6	8.0	1.3
400.0	401.8	1.8	16.0	0.5
600.0	603.2	3.2	24.0	0.5
800.0	805.8	5.8	32.0	0.7
1000.0	1007.0	7.0	40.0	0.7
1200.0	1212.4	12.4	48.0	1.0

For device 1 a deviation from the linear regression line of 0.3 µg/m³ (equivalent to 0.24 ppb) at zero and maximum 0,8 % of measured value at a concentrations higher than zero could be determined.

For device 2 a deviation from the linear regression line of 0.6 µg/m³ (equivalent to 0.48 ppb) at zero and maximum 1,3 % of measured value at a concentrations higher than zero could be determined.

The in the EN 14211 required quality criterion is for the component NO fulfilled.

6.5 Assessment

The two analysers meet the requirements of the guidelines.

Minimum requirement fulfilled? yes

6.6 Documentation

In Table 11 and Table 12 as well as in Figure 6 and Figure 7 the results of the group mean value investigations are given comprehensively in graphic and in tabular form. The single values are given in the appendix in Table 54 to Table 58.

Table 11: Statistical characteristics on basis of the group mean values for device 1, component NO₂

Characteristics device 1				
Standard deviation	s	=	0.990	
Coefficient of correlation	r	=	1.0000	
Y = b * x + c Slope	b	=	0.995	
Intercept	c	=	0.068	µg/m ³
Mean value	Measuring value	=	220.417	µg/m ³
Mean value	Expected value	=	219.458	µg/m ³

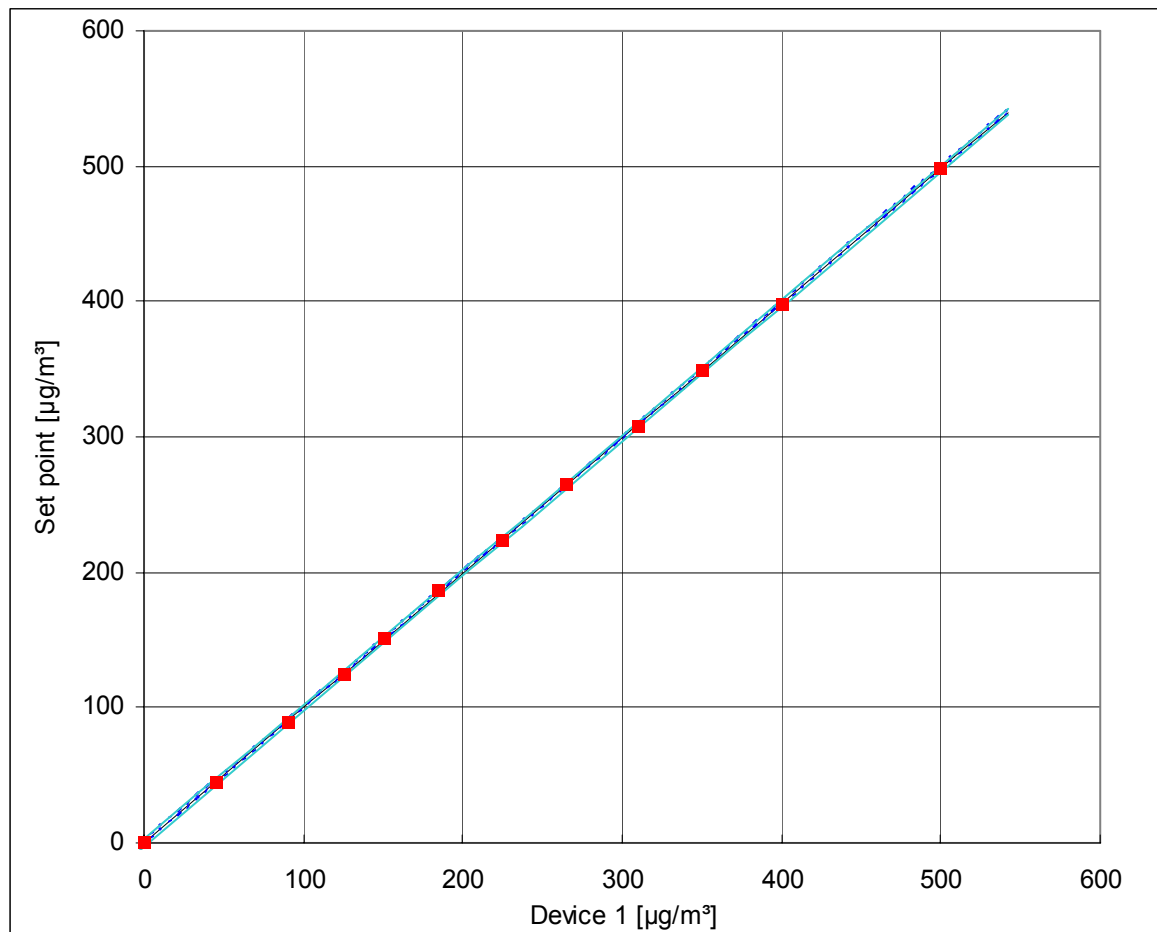


Figure 6: Analytical function from the group mean values for device 1, component NO₂

Table 12: Statistical characteristics on basis of the group mean values for device 2, component NO₂

Characteristics device 2				
Standard deviation	s	=	0.716	
Coefficient of correlation	r	=	1.0000	
Y = b * x + c	Slope	b	=	1.002
	Intercept	c	=	0.875 µg/m ³
Mean value	Measuring value	=	220.417	µg/m ³
Mean value	Expected value	=	221.703	µg/m ³

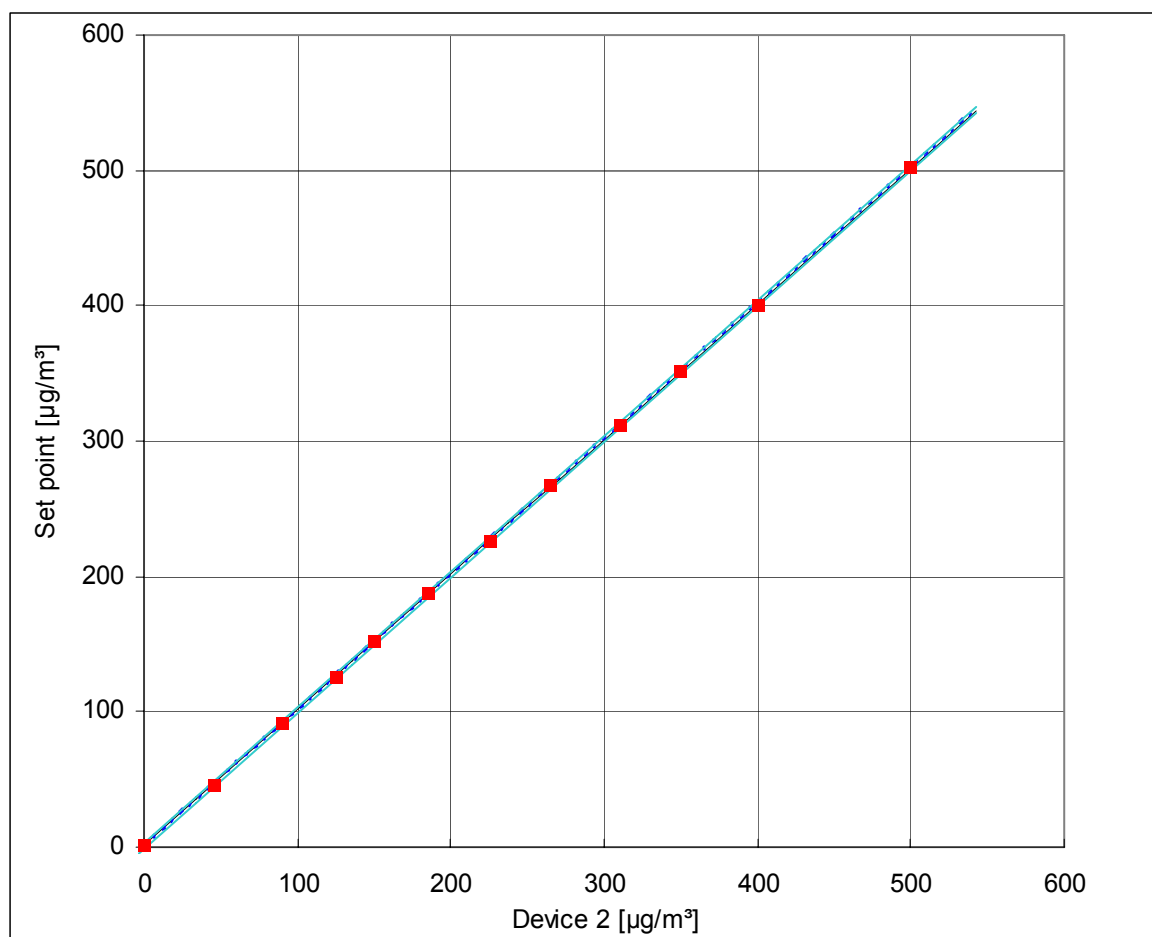


Figure 7: Analytical function from the group mean values for device 2, component NO₂

In Table 13 and Table 14 as well as in Figure 8 and Figure 9 the results of the group mean value investigations are given comprehensively in graphic and in tabular form for NO. The single values are given in the appendix in Table 59 to Table 63.

Table 13: Statistical characteristics on basis of the group mean values for device 1, component NO

Characteristics device 1				
Standard deviation	s	=	1,611	
Coefficient of correlation	r	=	1,0000	
Y = b* x + c Slope	b	=	1,007	
Intercept	c	=	-0,644	µg/m ³
Mean value	Measuring value	=	600,000	µg/m ³
Mean value	Expected value	=	603,494	µg/m ³

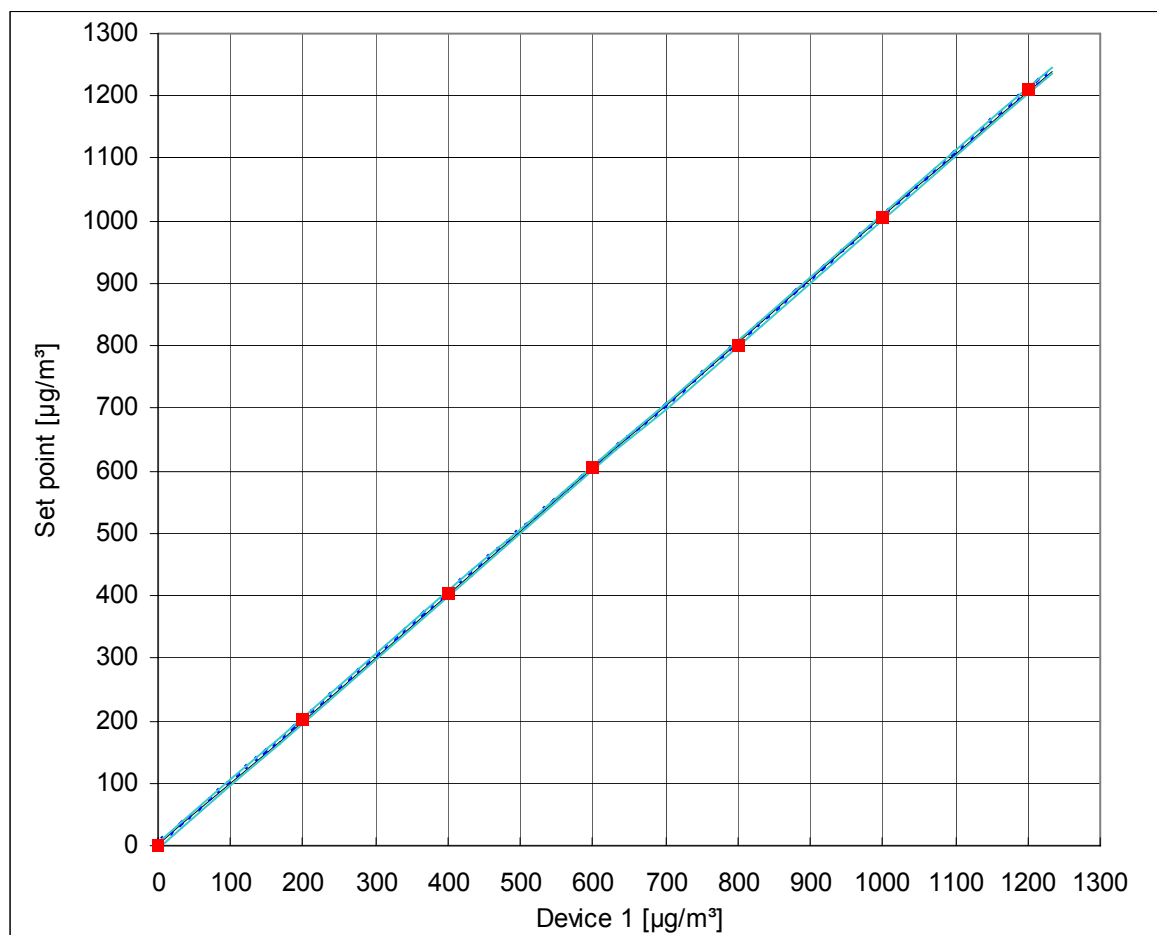


Figure 8: Analytical function from the group mean values for device 1, component NO

Table 14: Statistical characteristics on basis of the group mean values for device 2, component NO

Characteristics device 2				
Standard deviation	s	=	1.712	
Coefficient of correlation	r	=	1.0000	
Y = b * x + c	Slope	b	=	1.009
	Intercept	c	=	-0.393 µg/m ³
Mean value	Measuring value	=	600.000	µg/m ³
Mean value	Expected value	=	604.771	µg/m ³

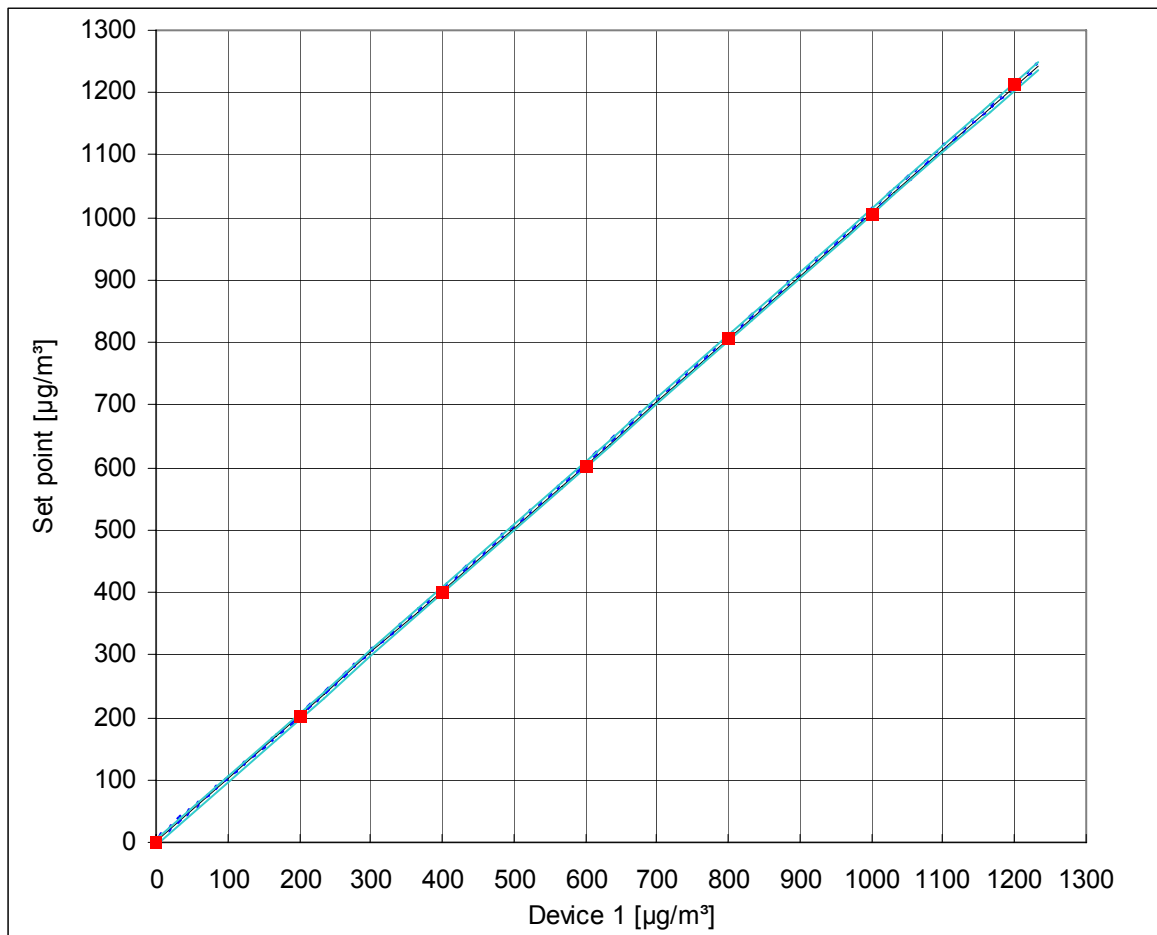


Figure 9: Analytical function from the group mean values for device 2, component NO

6.1 5.2.5 Detection limit

The detection limit of the measuring system shall be smaller or equal to reference value B_0 . The detection limit shall be determined in the field.

EN 14211; 8.4.6: Repeating standard deviation at zero for NO ≤ 1.0 ppb (corresponds to $1.25 \mu\text{g}/\text{m}^3$); at span ≤ 3.0 ppb (corresponds to $3.75 \mu\text{g}/\text{m}^3$)

6.2 Equipment

Zero gas and test gas in suitable concentrations.

6.3 Testing

The examination was done through alternating application of zero and reference gas. The detection limit is determined in the lab and at the end of the field test. The detection limit is determined according to the guideline VDI 4203 part 3 from 15 measured values each. According to the EN 14211 for the determination of the detection limit 20 measured values each are necessary. The EN 14211 demands only for one time of testing of the detection limit in the lab. In order to meet the requirements of both guidelines, the detection limit was determined in the lab with 20 single measured values in each case and in the field test with 15 single measured values in each case.

6.4 Evaluation

On basis of the measuring data recorded in lab and field the evaluation was carried out. The test criterion of the detection limit is regarded as fulfilled, if the detection limit in the lab and field is smaller than $B_0 = 3 \mu\text{g}/\text{m}^3$. The Table 15 show in conclusion the results of the investigations of NO₂. The measured values are stated in Table 18 and Table 19.

Table 15: Survey of the detection limits for NO₂

Measuring		Zero point		Span point	
		Lab	Field	Lab	Field
		$\mu\text{g}/\text{m}^3$	$\mu\text{g}/\text{m}^3$	$\mu\text{g}/\text{m}^3$	$\mu\text{g}/\text{m}^3$
Number	n	15	15	15	15
Mean value	x	1.67	-1.36	2.63	-1.45
Repeating standard deviation	s	0.27	0.73	0.45	0.42
DL = 3 * standard deviation	3s	0.81	2.19	1.35	1.26
Requirements of VDI 4202	$\mu\text{g}/\text{m}^3$	3	3	3	3
Met requirements?		yes	yes	yes	yes

The repeating standard deviation of this measurement demanded for in EN 14211 is calculated as follows:

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

In this case is

- s_r the repeating standard deviation
- x_i the i-th measurement
- \bar{x} the mean value of the 20 measurements
- n the number of the measurements

The Table 16 and Table 17 show in conclusion the results of the investigations of NO. The measured values are stated in Table 20 and Table 21.

Table 16: Survey of the detection limits for NO at the zero point

Measuring		Unit 1	Unit 2
		Laboratory	Laboratory
		ppb	ppb
Number	n	15	15
Mean value	x	-0.14	-0.16
Repeating standard deviation	s	0.17	0.21
Requirement of EN 14211	ppb	1	1
Met requirements?		yes	yes

The required criterion for the repeating standard deviation at the zero point for the component NO smaller than 1 ppb is fulfilled.

Table 17: *Survey of the detection limits for the NO channel at the span point*

Measuring		Unit 1	Unit 2
		Laboratory	Laboratory
		ppb	ppb
Number	n	20	20
Mean value	x	581.3	585.0
Repeating standard deviation	s	1.13	1.21
Requirement of EN 14211	ppb	3	3
Met requirements?		yes	yes

The required criterion for the repeating standard deviation at the span point for the component NO smaller than 3 ppb is fulfilled.

6.5 Assessment

The detection limit is within the minimum requirements.

Minimum requirement fulfilled? yes

6.6 Documentation

Table 18: Detection limit NO₂ laboratory

Measurement No.	Unit 1 µg/m ³	Unit 2 µg/m ³
1	1.2	1.8
2	1.2	1.9
3	1.6	2.8
4	1.6	2.9
5	1.7	3
6	2.1	3.2
7	1.7	3
8	1.5	2.2
9	1.8	2.9
10	2.1	3.1
11	1.8	2.9
12	1.8	2.6
13	1.9	2.7
14	1.6	2.3
15	1.4	2.1

Table 19: Detection limit NO₂ field test

Measurement No.	Unit 1 µg/m ³	Unit 2 µg/m ³
1	-1.4	-1.4
2	-1.4	-1.4
3	-1.8	-1.6
4	-1.8	-1
5	-1.8	-1
6	-1.6	-1.4
7	-0.8	-1.4
8	-1.6	-1.8
9	-2	-2
10	-1.8	-0.4
11	1	-1.6
12	-1.4	-2
13	-1.8	-1.6
14	-1.2	-1.8
15	-1	-1.4

Table 20: *Repeating standard deviation NO zero point, laboratory*

Measurement No.	Unit 1 ppb	Unit 2 ppb
1	-0.2	-0.1
2	-0.1	-0.1
3	-0.4	0
4	-0.1	-0.1
5	-0.1	-0.2
6	-0.4	-0.3
7	-0.3	-0.5
8	-0.1	0.1
9	0	-0.1
10	-0.1	-0.2
11	-0.3	0.2
12	0.1	0.1
13	-0.1	-0.5
14	0.2	-0.4
15	-0.2	-0.3

Table 21: *Repeating standard deviation NO span point, laboratory*

Measurement No.	Unit 1 ppb	Unit 2 ppb
1	580	586
2	583	584
3	582	583
4	582	585
5	580	586
6	582	587
7	581	584
8	583	586
9	581	585
10	581	583
11	579	585
12	582	584
13	582	586
14	580	587
15	581	584
16	583	584
17	582	585
18	580	586
19	581	586
20	581	584

6.1 5.2.6 Response time

The response time (90% time) of the measuring system shall be smaller or equal to 5 % of the averaging time 180 s).

EN 14211: 8.4.3 Response time (rise) and response time (fall) each ≤ 180 s. Difference between rise and fall time ≤ 10 % relative Difference or 10 s, depending on which value is higher.

6.2 Equipment

Zero and reference gas in suitable concentration as well as a data recording system were used for the determination of the response time.

6.3 Testing

The rise and fall times were registered by means of data recording system and examined for the 90 %-time.

6.4 Evaluation

The rise and fall times are to be taken from Table 22 and Table 23.

Table 22: Increasing and falling response times of the two measuring units for the component NO₂

Start value [µg/m ³]	Final value 90% [µg/m ³]	Time unit 1 [s]	Time unit 2 [s]	Requirement according to VDI 4202 and EN 14211 [s]	Requirement fulfilled?
0	360	50	52	180	yes
400	40	55	53	180	yes
Difference		5	2		
0	360	48	50	180	yes
400	40	55	55	180	yes
Difference		7	5		
0	360	52	51	180	yes
400	40	54	53	180	yes
Difference		2	2		
0	360	48	48	180	yes
400	40	52	53	180	yes
Difference		4	5		

For device 1, a maximum t_r of 52 s, a maximum t_f of 55 s and a t_d of 9.1 % has been calculated for NO₂.

For device 2, a maximum t_r of 52 s, a maximum t_f of 55 s and a t_d of 6.5 % has been calculated for NO₂.

Table 23: *Increasing and falling response times of the two measuring units for the component NO*

Start value [µg/m³]	Final value 90% [µg/m³]	Time unit 1 [s]	Time unit 2 [s]	Requirement according to VDI 4202 and EN 14211 [s]	Requirement fulfilled?
0	900	76	74	180	yes
1000	100	78	77	180	yes
Difference		2	3		
0	900	78	78	180	yes
1000	100	83	80	180	yes
Difference		5	2		
0	900	77	79	180	yes
1000	100	80	81	180	yes
Difference		3	3		
0	900	78	76	180	yes
1000	100	78	79	180	yes
Difference		0	3		

For device 1 a maximum t_r of 78 s, a maximum t_f of 83 s and a t_d of 3.2 % has been calculated for NO.

For device 2 a maximum t_r of 79 s, a maximum t_f of 81 s and a t_d of 3.3 % has been calculated for NO.

According to EN 14211 in addition the difference between rise and fall time may be at maximum 10 % or 10 s depending on which value is higher.

The relative difference of the response time is calculated according to following equation:

$$t_d = \left| \frac{t_r - t_f}{t_r} \right| \times 100\%$$

With: t_d the relative difference between rise - and fall time
 t_r the response time (rise) (Mean value of 4 measurements) (s)
 t_f the response time (fall) (Mean value of 4 measurements) (s)

Regarding EN 14211 is a response time of 180 s for NO allowed. In addition the difference between rise and fall time may be at maximum 10 % or 10 s.

As stated in Table 23 both requirements are fulfilled.

6.5 Assessment

The maximal permissible response time of 180 seconds is fallen below clearly.. The difference between rise and fall time is smaller than 10 seconds as required in the EN 14211.

Minimum requirement fulfilled? yes

6.6 Documentation

Here not essential.

6.1 5.2.7 Dependence of the zero point on ambient temperature

The temperature dependence of the measured value at zero shall not exceed the reference value B_0 if ambient temperature is changed by 15 K in the range of +5 °C to +20 °C or 20 K in the range of +20 °C und +40 °C.

EN 14211; 8.4.9: Sensitivity coefficient of the ambient temperature for NO $\leq 3,0$ nmol/mol/K (corresponds to 3,0 ppb/K or 3,75 $\mu\text{g}/\text{m}^3\text{K}$).

6.2 Equipment

Climate chamber, reference gases.

6.3 Testing

According to VDI 4202 part 1 the temperature dependence of the zero point for NO₂ is to be tested between + 5°C and + 40°C. The following temperature levels are tested subsequently in this case: 20°C → 5°C → 20°C → 40°C → 20°C. The test gases are applied three times per temperature point and the temperature program is run through for three times.

Differing from that the EN 14211 demands for an examination for NO in the temperature range of 0°C to + 30°C. The following temperature points are tested subsequently in this case: 20°C → 0°C → 20°C → 30°C → 20°C.

6.4 Evaluation

As stated in Table 24 the measured values don't exceed the allowed deviations fulfil the requirements for the component NO₂. The greatest average deviation of both devices 2.46 $\mu\text{g}/\text{m}^3$ for device 1 and 2.90 $\mu\text{g}/\text{m}^3$ for device 2 have been taken for the calculation of total uncertainty of VDI 4202.

The results of the investigations for the sensitivity coefficient on zero for the component NO are stated in Table 25.

The sensitivity coefficient according to EN 14211 for NO results from following equation:

$$b_{st} = \left| \frac{x_T - \frac{x_1 + x_2}{2}}{T - T_1} \right|$$

In this case is:

b_{st}	the dependence of the measured value from the ambient temperature (mg/m ³)
x_T	the mean value of the measurements at T_{min} or T_{max} (mg/m ³)
x_1	the first mean value of the measurements at T_1 (mg/m ³)
x_2	the second mean value of the measurements at T_1 (mg/m ³)
T_1	the ambient air temperature in the lab (K)
T	the ambient air temperature T_{min} or T_{max} (K)

The determined sensitivity coefficients regarding to EN 14211 are:

At 0°C:

Unit 1: 0.01 ppb/K

Unit 2: 0.01 ppb/K

At 30°C:

Unit 1: 0.05 ppb/K

Unit 2: 0.18 ppb/K

The maximum coefficient of this respectively the coefficient of the investigations on the Span-point has been used for the calculation of the total uncertainty regarding EN 14211.

6.5 Assessment

The change of the zero point is at all ambient temperatures within the limit of the minimum requirement. The criteria of the EN 14211 are fulfilled as well.

Minimum requirement fulfilled? yes

6.6 Documentation

Table 24: Single values of the dependence of the NO₂ zero point from the ambient temperature

Temperature [°C]	Unit 1 Rep. 1	Rep. 2	[µg/m³] Rep. 3	Unit 2 Rep. 1	Rep. 2	[µg/m³] Rep. 3
20	0.10	0.20	0.10	0.00	0.10	0.20
	0.30	0.30	0.20	-0.10	0.00	0.00
	0.30	0.20	0.20	0.20	0.10	0.00
Average	0.23	0.23	0.17	0.03	0.07	0.07
5	-1.00	-0.70	-1.30	-0.90	-1.10	
	-0.50	-1.00	-1.10	-0.90	-0.80	-0.90
	-0.80	-0.90	-0.90	-0.70	-0.90	-1.00
Average	-0.77	-0.87	-1.10	-0.83	-0.93	-0.95
Deviation to 20°C						
	-1.00	-1.10	-1.27	-0.87	-1.00	-1.02
20	-0.50	0.00	-0.30	-0.50	-0.30	-0.30
	0.00	-0.40	0.00	-0.40	-0.50	-0.40
	-0.20	-0.30	-0.20	-0.30	-0.40	-0.10
Average	-0.23	-0.23	-0.17	-0.40	-0.40	-0.27
40	2.70	2.20	1.90	2.50	2.60	3.00
	2.40	2.50	2.10	2.50	2.30	2.40
	2.60	1.80	2.00	2.60	2.30	2.70
Average	2.57	2.17	2.00	2.53	2.40	2.70
Deviation to 20 °C						
	2.80	2.40	2.17	2.93	2.80	2.97
20	-0.10	-0.30	-0.10	-0.30	-0.10	-0.10
	-0.40	-0.40	-0.30	-0.20	-0.10	-0.20
	-0.20	-0.20	-0.10	-0.10	0.00	-0.10
Average	-0.23	-0.30	-0.17	-0.20	-0.07	-0.13

Table 25: Single values of the dependence of the NO zero point from the ambient temperature

Temperature [°C]	Unit 1 Rep. 1	[ppb] Rep. 2	Rep. 3	Unit 2 Rep. 1	[ppb] Rep. 2	Rep. 3
20	-0.10	0.00	0.00	0.00	0.00	-0.10
	0.00	-0.10	0.10	-0.10	-0.20	-0.10
	-0.10	-0.20	0.00	-0.10	0.00	-0.10
Average	-0.07	-0.10	0.03	-0.07	-0.07	-0.10
0	-0.30	-0.30	-0.40	-0.30	-0.40	-0.30
	-0.30	-0.20	-0.30	-0.20	-0.30	-0.40
	-0.40	-0.30	-0.20	-0.20	-0.40	-0.30
Average	-0.33	-0.27	-0.30	-0.23	-0.37	-0.33
Deviation to 20°C	-0.27	-0.17	-0.33	-0.17	-0.30	-0.23
20	-0.10	-0.10	-0.10	-0.10	-0.10	-0.10
	-0.20	-0.20	-0.10	0.00	-0.10	-0.20
	0.00	-0.10	0.00	0.00	-0.20	-0.20
Average	-0.10	-0.13	-0.07	-0.03	-0.13	-0.17
30	0.40	0.50	0.50	1.80	1.80	1.60
	0.50	0.40	0.30	1.90	1.80	1.80
	0.30	0.50	0.30	1.70	1.70	1.80
Average	0.40	0.47	0.37	1.80	1.77	1.73
Deviation to 20 °C	0.50	0.60	0.43	1.83	1.90	1.90
20	-0.10	0.00	-0.10	0.00	0.00	0.10
	0.00	-0.10	0.00	0.00	-0.10	0.10
	-0.10	-0.20	-0.10	-0.10	0.00	0.10
Average	-0.07	-0.10	-0.07	-0.03	-0.03	0.10

6.1 5.2.8 Dependence of the measured value on ambient temperature

The temperature dependence of the measured value in the range of reference value B_1 shall not exceed 5 % of the measured value if ambient temperature is changed by 15 K in the range of +5 °C to +20 °C or 20 K in the range of +20 °C to +40 °C.

EN 14211; 8.4.9: Sensitivity coefficient of the ambient temperature for NO $\leq 3.0 \text{ nmol/mol/K}$ (corresponds to 3.0 ppb/K or 3.75 $\mu\text{g/m}^3\text{K}$).

6.2 Equipment

Climate chamber.

6.3 Testing

According to VDI 4202 part 1 the temperature dependence of the span point is to be tested between + 5°C and + 40°C for NO₂. The following temperature levels are tested subsequently in this case: 20°C → 5°C → 20°C → 40°C → 20°C. The test gases are applied three times per temperature point and the temperature program is run through for three times.

Differing from that the EN 14211 demands for an examination in the temperature range of 0°C to + 30°C for NO. The following temperature points are tested subsequently in this case: 20°C → 0°C → 20°C → 30°C → 20°C.

6.4 Evaluation

As stated in Table 26 the measured values don't exceed the allowed deviations fulfil the requirements for the component NO₂. The greatest average deviation of both devices 1.94 $\mu\text{g/m}^3$ for device 1 and -1.39 $\mu\text{g/m}^3$ for device 2 have been taken for the calculation of total uncertainty of VDI 4202.

The results of the investigations for the sensitivity coefficient on span for the component NO are stated in Table 27.

The sensitivity coefficient according to EN 14211 for NO results from following equation:

$$b_{st} = \left| \frac{x_T - \frac{x_1 + x_2}{2}}{T - T_1} \right|$$

In this case is:

b_{st}	the dependence of the measured value from the ambient temperature ($\mu\text{g}/\text{m}^3$)
x_T	the mean value of the measurements at T_{\min} or T_{\max} ($\mu\text{g}/\text{m}^3$)
x_1	the first mean value of the measurements at T_1 ($\mu\text{g}/\text{m}^3$)
x_2	the second mean value of the measurements at T_1 ($\mu\text{g}/\text{m}^3$)
T_1	the ambient air temperature in the lab (K)
T	the ambient air temperature T_{\min} or T_{\max} (K)

The determined sensitivity coefficients according to EN 14211 are:

At 0°C:

Unit 1: 0.26 ppb/K

Unit 2: 0.25 ppb/K

At 30°C:

Unit 1: 0.39 ppb/K

Unit 2: 0.37 ppb/K

The maximum coefficient of this respectively the coefficient of the investigations on the Zero-point has been used for the calculation of the total uncertainty regarding EN 14211.

6.5 Assessment

The change of the span point is at all ambient temperatures within the limit of the minimum requirement. The criterion of the EN 14211 is fulfilled also.

Minimum requirement fulfilled? yes

6.6 Documentation

Table 26: *Single values of the dependence of the NO₂ span point from the ambient temperature*

Temperature [°C]	Unit 1 [µg/m ³]			Unit 2 [µg/m ³]		
	Rep. 1	Rep. 2	Rep. 3	Rep. 1	Rep. 2	Rep. 3
20	58.78	59.15	58.89	58.93	58.88	58.86
	58.85	58.95	59.06	58.79	58.60	58.71
	58.75	59.10	58.97	58.80	58.77	58.82
Average	58.79	59.07	58.97	58.84	58.75	58.80
5	57.40	57.64	57.58	57.39	57.31	57.55
	57.58	57.51	57.45	57.35	57.33	57.50
	57.42	57.55	57.55	57.36	57.30	57.53
Average	57.47	57.57	57.53	57.37	57.31	57.53
Deviation to 20°C	-1.33	-1.50	-1.45	-1.47	-1.44	-1.27
20	58.76	58.60	58.85	58.67	58.71	58.68
	58.70	58.52	58.70	58.70	58.65	58.70
	58.64	58.70	58.68	58.72	58.70	58.67
Average	58.70	58.61	58.74	58.70	58.69	58.68
40	60.65	60.41	60.82	58.48	57.95	57.48
	60.61	60.39	60.93	58.22	57.70	57.37
	60.60	60.30	60.94	58.30	57.88	57.59
Average	60.62	60.37	60.90	58.33	57.84	57.48
Deviation to 20 °C	1.92	1.76	2.15	-0.36	-0.84	-1.20
20	58.18	58.21	58.40	58.36	58.40	58.27
	58.25	58.38	58.13	58.24	58.25	58.45
	58.10	58.09	58.22	58.50	58.03	58.51
Deviation	58.18	58.23	58.25	58.37	58.23	58.41

Table 27: Single values of the dependence of the NO span point from the ambient temperature

Temperature [°C]	Unit 1 [ppb]			Unit 2 [ppb]		
	Rep. 1	Rep. 2	Rep. 3	Rep. 1	Rep. 2	Rep. 3
20	623.00	623.00	624.00	624.00	624.00	623.00
	623.00	622.00	623.00	624.00	622.00	624.00
	624.00	624.00	624.00	623.00	624.00	623.00
Average	623.33	623.00	623.67	623.67	623.33	623.33
0	630.00	628.00	628.00	629.00	628.00	628.00
	628.00	629.00	628.00	629.00	629.00	627.00
	628.00	628.00	629.00	627.00	627.00	629.00
Average	628.67	628.33	628.33	628.33	628.00	628.00
Deviation to 20°C	5.33	5.33	4.67	4.67	4.67	4.67
20	623.00	622.00	624.00	623.00	623.00	623.00
	624.00	624.00	623.00	622.00	622.00	623.00
	623.00	623.00	624.00	622.00	623.00	623.00
Average	623.33	623.00	623.67	622.33	622.67	623.00
30	619.00	619.00	618.00	619.00	618.00	620.00
	620.00	619.00	620.00	618.00	619.00	620.00
	620.00	618.00	619.00	618.00	620.00	619.00
Average	619.67	618.67	619.00	618.33	619.00	619.67
Deviation to 20 °C	-3.67	-4.33	-4.67	-4.00	-3.67	-3.33
20	623.00	623.00	622.00	623.00	623.00	622.00
	622.00	624.00	622.00	622.00	622.00	623.00
	622.00	623.00	623.00	623.00	622.00	624.00
Average	622.33	623.33	622.33	622.67	622.33	623.00

6.1 5.2.9 Drift of zero point

The temporal change in the measured value at zero concentration shall not exceed the reference value B_0 in 24 h and in the maintenance interval.

EN 14211; 8.5.4 Long term drift at zero NO ≤ 5.0 nmol/mol (corresponds to 5.0 ppb or 6.25 $\mu\text{g}/\text{m}^3$).

6.2 Equipment

For the determination of the zero point drift synthetic air has been used.

6.3 Testing

The offering of zero air was made over a time interval of 15 minutes daily. The last 5 minutes of this time interval were recorded, averaged and evaluated. The test gas offerings have not been done automatically, so that there are no test gas offerings at the weekend.

6.4 Evaluation

The following graphics show the process of the test gas offerings for both analysers during three months field test operation.

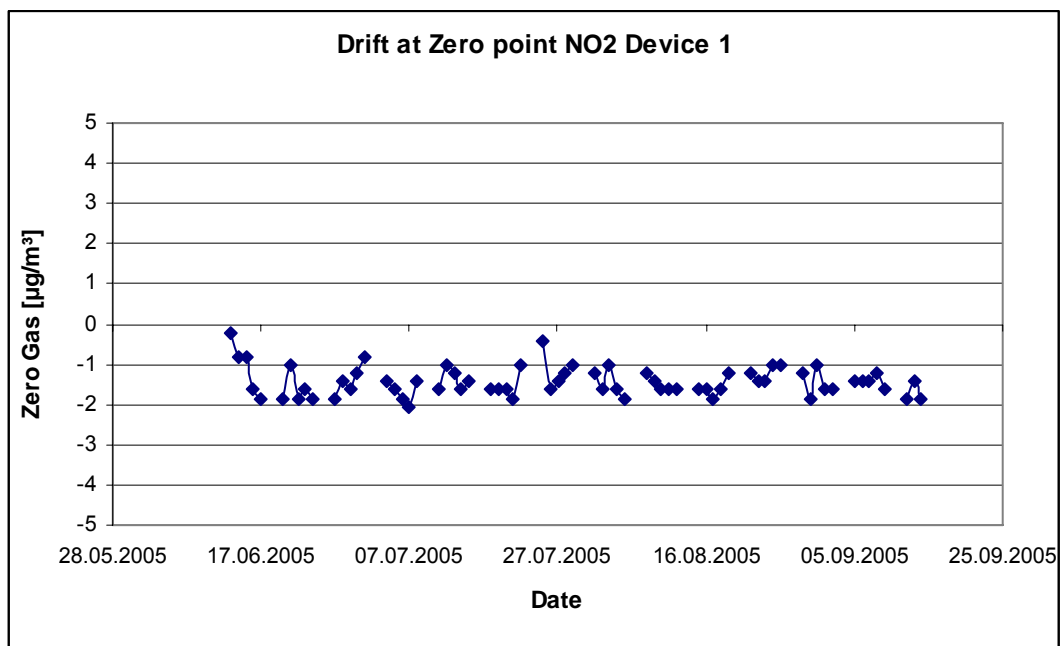


Figure 10: Temporal change of the NO₂ zero points during the field test, unit 1

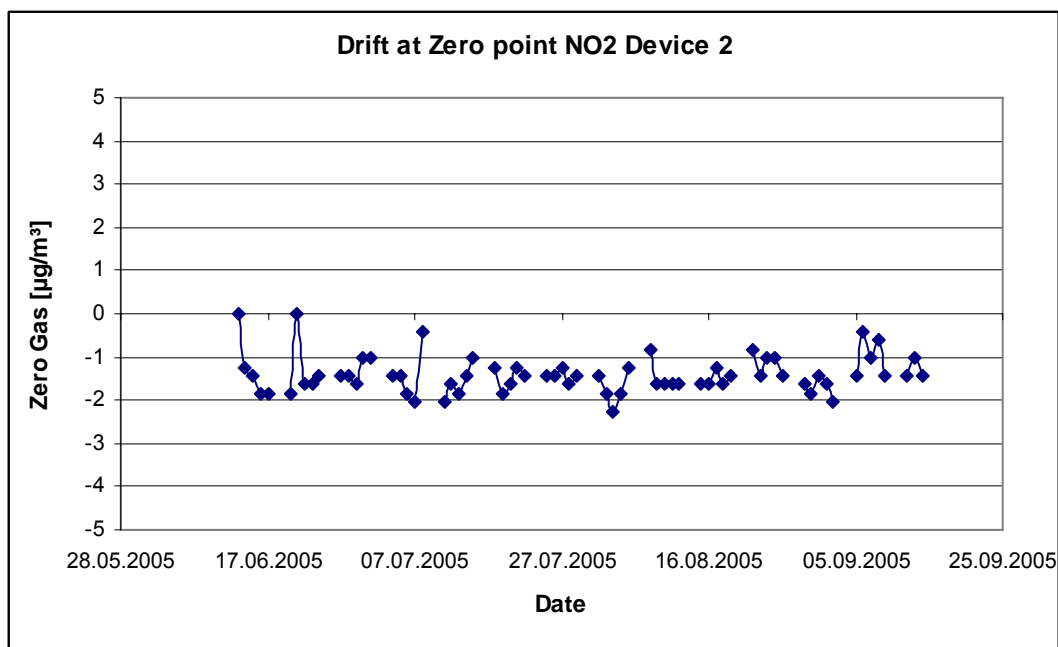


Figure 11: Temporal change of the NO₂ zero points during the field test, unit 2

The minimum standard requires, that the temporal change of the measured value at the zero point in 24 h and in the maintenance interval must not exceed the basic value B₀ (corresponds 3 µg/m³ for NO₂).

No exceeding of the 24 hour drift results from the data derived. The calculation of the regression functions gives the following values for the zero point drift for analyser 1 and 2 in the 24 hour interval for NO₂:

The middle temporal change in 24 h conducted during the field test:

Unit 1: -0.0013 µg/(m³*d)

Unit 2: 0.0003 µg/(m³*d)

In the maintenance interval of a month the middle temporal change conducts:

Unit 1: -0.039 µg/(m³*month)

Unit 2: -0.009 µg/(m³*month)

The examination of the zero point drift during the field test according to EN 14211 shows the following results for the component NO:

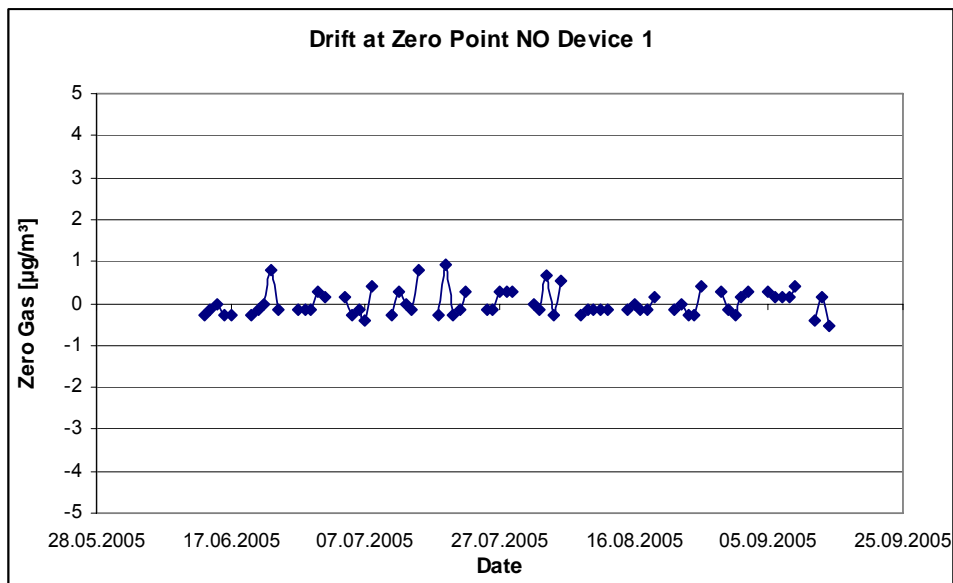


Figure 12: Temporal change of the NO zero points during the field test, unit 1

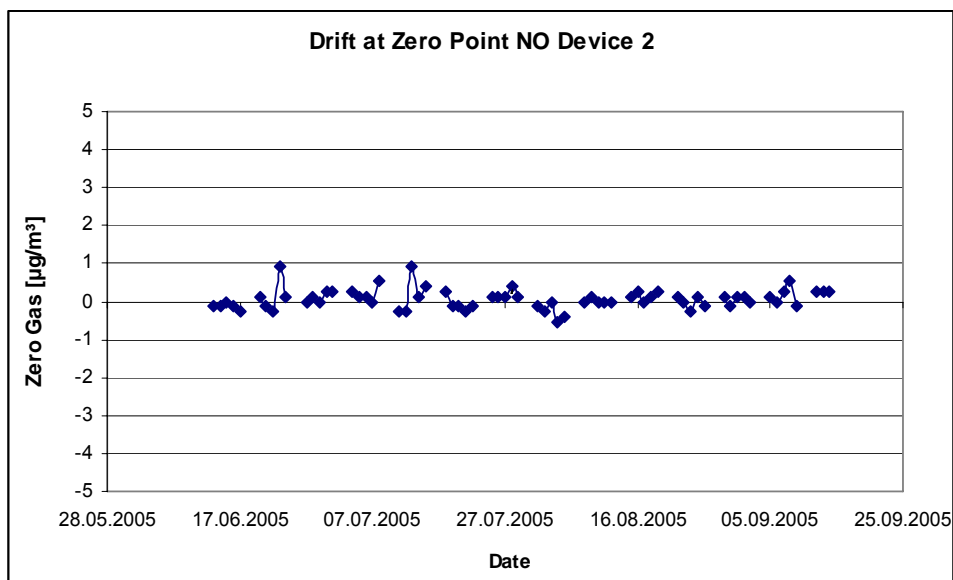


Figure 13: Temporal change of the NO zero points during the field test, unit 2

The calculation of the regression functions gives the following values for the zero point drift for analyser 1 and 2 in the 24 hour interval for NO:

The middle temporal change in 24 h conducted during the field test:

Unit 1: 0.0004 ppb/d

Unit 2: 0.0004 ppb/d

In the maintenance interval of a month the middle temporal change conducts:

Unit 1: 0.012 ppb/month

Unit 2: 0.012 ppb/month

The allowed long term drift according to 14211 for NO at the zero point is 5 ppb. This minimum requirements is for both analysers kept surely.

6.5 Assessment

The zero point drifts meets the minimum requirements. Also the long-term drift of the EN 14211 fulfils the required criterion.

Minimum requirement fulfilled? yes

6.6 Documentation

See Figure 10 to Figure 13.

6.1 5.2.10 Drift of measured value

The temporal change in the measured value in the range of reference of reference value B_1 shall not exceed 5 % of B_1 in 24 h and in the maintenance interval.

EN 14211; 8.5. Long term drift at span level for NO ≤ 5 % of the certified range (corresponds for an NO range of 0 to 1200 $\mu\text{g}/\text{m}^3$ to an allowed deviation of 60 $\mu\text{g}/\text{m}^3$).

6.2 Equipment

For the determination of the span point drift of the NO₂ channel a test gas from an permeation system has been used. The NO tests have been done with an test gas from cylinders.

6.3 Testing

The offering of zero air was made over a time interval of 15 minutes daily. The last 5 minutes of this time interval were recorded, averaged and evaluated. The test gas offerings have not been done automatically, so that there are no test gas offerings at the weekend.

6.4 Evaluation

The following graphics show the process of the test gas offerings for both analysers during three months field test operation.

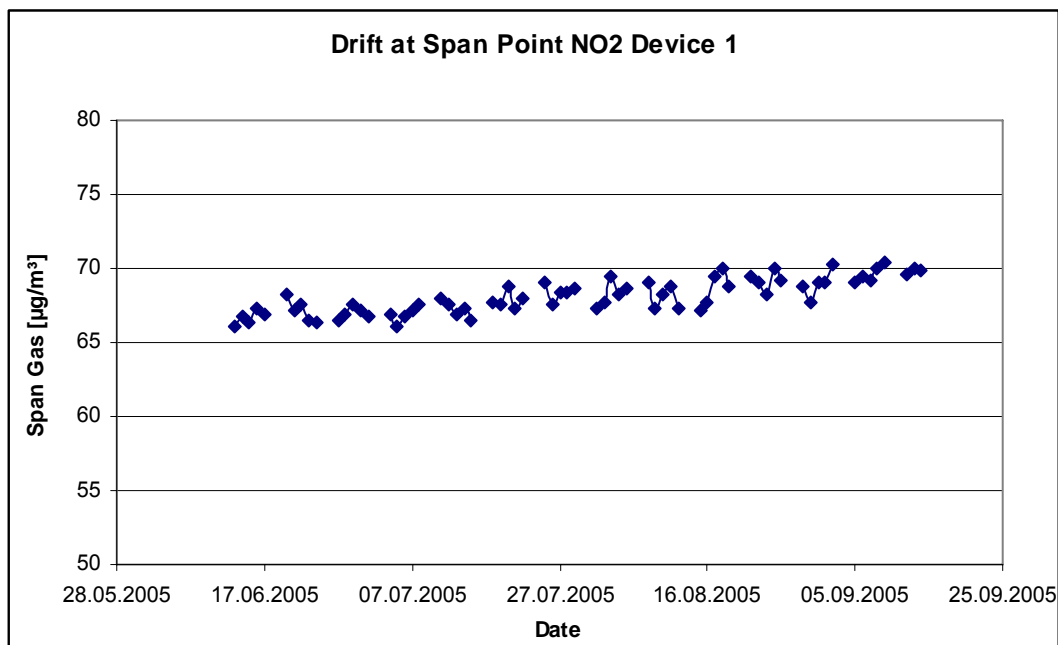


Figure 14: Temporal change of the NO₂ span points during the field test, unit 1

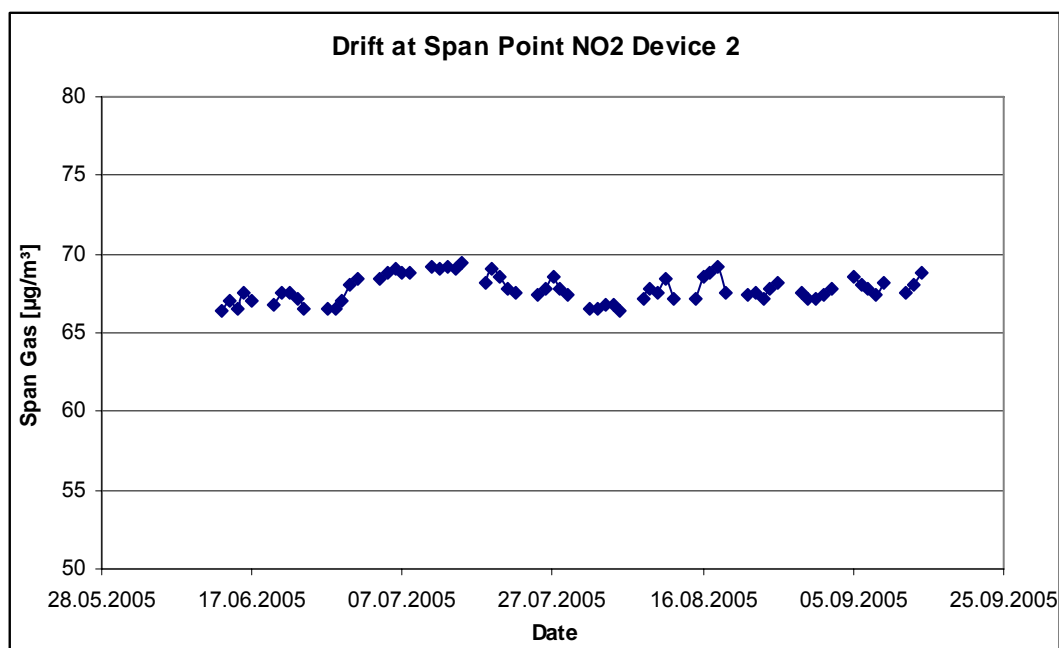


Figure 15: Temporal change of the NO₂ span points during the field test, unit 2

The minimum standard requires, that the temporal change of the measured value in 24 h at the span point and in the maintenance interval must not exceed 5% of the basic value B₁ (corresponds 3 µg/m³ for NO₂).

Out of the data results no exceeding of the 24 hour drift. The calculation of the regression function gives the following values for the span point drift for analyser 1 and 2 in the 24 hour interval for NO₂ :

The middle temporal change in 24 h conducted during the field test:

Unit 1: 0.0341 µg/(m³*d)

Unit 2: 0.003 µg/(m³*d)

In the maintenance interval of a month the middle temporal change conducts:

Unit 1: 1.023 µg/(m³*month)

Unit 2: 0.090 µg/(m³*month)

The examination of the span point drift during the field test according to EN 14211 shows the following results for the component NO.

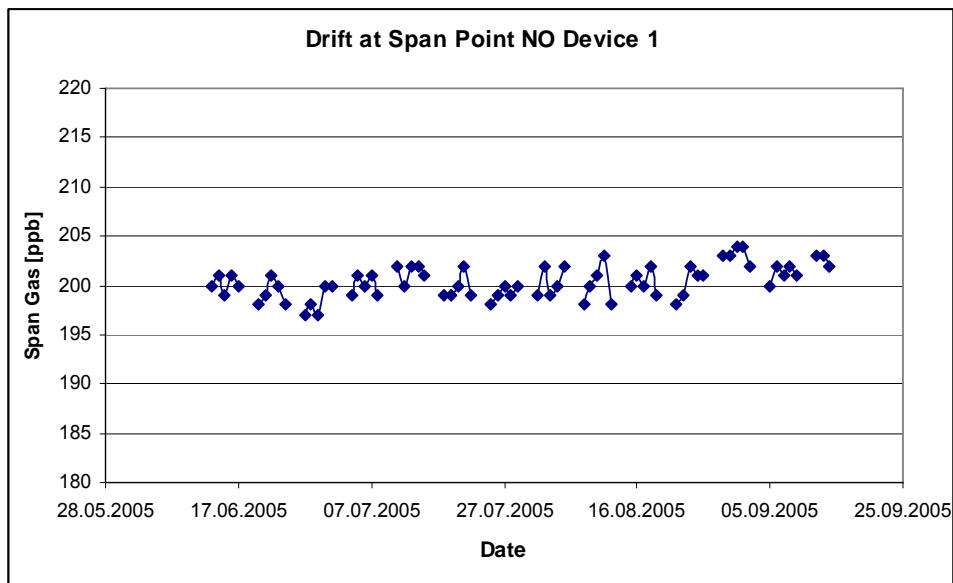


Figure 16: Temporal change of the NO span points during the field test, unit 1

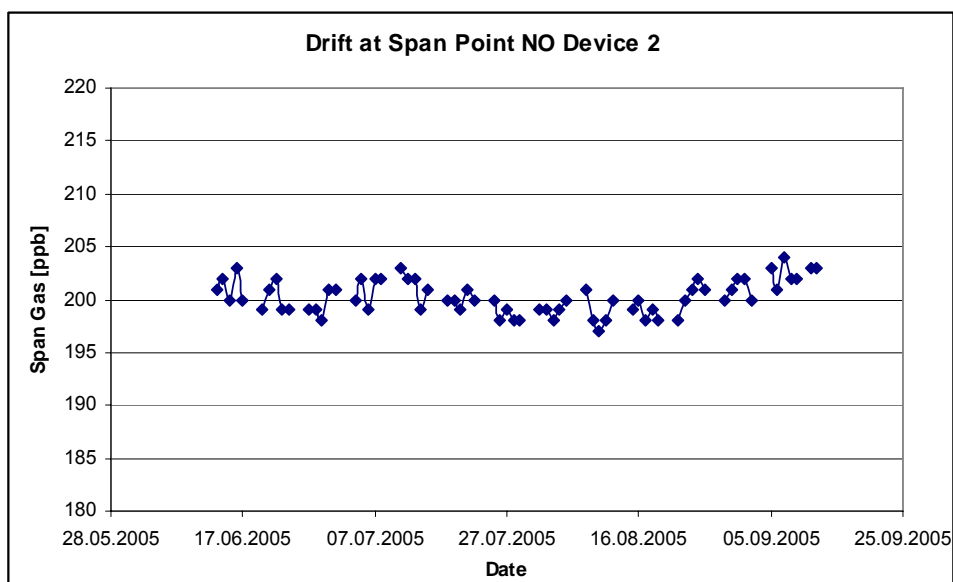


Figure 17: Temporal change of the NO span points during the field test, unit 2

The calculation of the regression function gives the following values for the span point drift for analyser 1 and 2 in the 24 hour interval for NO:

The middle temporal change in 24 h conducted during the field test:

Unit 1: 0.029 ppb/d

Unit 2: 0.007 ppb/d

In the maintenance interval of a month the middle temporal change conducts:

Unit 1: 0.87 ppb/month = 0.09 % of range

Unit 2: 0.21 ppb/month = 0.02 % of range

The allowed long term drift according to EN 14211 for NO at the span point is 5 % of the maximum of the certifying range (corresponds to an maximum deviation of 48 ppb = 60 µg/m³). This minimum requirements is kept surely for both analysers.

6.5 Assessment

The span point drift meets the minimum requirements . Also the long-term drift of the EN 14211 fulfils the required criterion for NO.

Minimum requirement fulfilled? yes

6.6 Documentation

See Figure 14 to Figure 17.

6.1 5.2.11 Cross-sensitivities

The absolute values of the sum of the positive and the sum of the negative deviations caused by cross-sensitivities of interfering components in the measured sample shall not exceed B_0 at the zero point and shall not exceed 3 % of B_2 in the range of B_2 . The concentration of interfering components shall correspond to the B_2 value of the respective interfering component. If reference values have not been specified, the test institute shall specify and declare suitable reference values in agreement with other test institutes. Especially the components listed in table 1 shall be taken into account in the check of cross-sensitivities. If necessary, additional components shall be taken into account on the basis of the measurement method.

EN 14211; 8.4.11: interfering components at zero and the concentration c_i (level of the hourly limit value). The allowed deviation for NO is ≤ 5 nmol/mol (corresponds to 5 ppb or 6,25 $\mu\text{g}/\text{m}^3$) for the interferents H₂O, CO₂ and NH₃, $\leq 2,0$ nmol/mol (corresponds to 2 ppb or 2,5 $\mu\text{g}/\text{m}^3$) for ozone.

6.2 Equipment

The test gas concentrations were made by an permeation system. The interferents are added to the test gas flow by an mass flow controller.

6.3 Testing

For the determination of the cross-sensitivities the components listed in Table 28 have been taken into account. On the basis of the measuring method additional components are considered.

Table 28: Interfering components and values

Interferent	Value
CO ₂	700 mg/m ³
CO	60 mg/m ³
H ₂ O	30 % to 90 % relative humidity
SO ₂	700 $\mu\text{g}/\text{m}^3$
NO	100 $\mu\text{g}/\text{m}^3$ to 1000 $\mu\text{g}/\text{m}^3$
NO ₂	400 $\mu\text{g}/\text{m}^3$
N ₂ O	500 $\mu\text{g}/\text{m}^3$
H ₂ S	30 $\mu\text{g}/\text{m}^3$
NH ₃	30 $\mu\text{g}/\text{m}^3$
O ₃	360 $\mu\text{g}/\text{m}^3$
Benzol	1 mg/m ³

6.4 Evaluation

The differences detected are given in the following table with and without interfering component for the zero and span point of the two analysers. At the bottom of the table the sums of the positive and the negative deviations are summarized. The values are to be compared with the minimum requirement that demands for a deviation of the positive and negative sums at the zero point of 3 µg/m³ (B₀) and a deviation of 12 µg/m³ (3 % of B₂) at the span point according to VDI 4203.

Table 29: Cross-sensitivities Thermo 42i for the NO₂ channel

Interferent		Analyser 1		Analyser 2	
		Deviation [µg/m ³]		Deviation [µg/m ³]	
	mg/m ³	ZP	SP	ZP	SP
CO ₂	SL				
	700	0.17	-2.33	0.16	-0,67
CO	SL				
	60	-0.14	1.67	-0.14	0,66
H ₂ O	SL				
	ca. 50 % rel.	1.16	-4.67	0.97	-5,00
SO ₂	SL				
	0,7	0.13	-1.00	-0.07	0,00
NO	SL				
	1	-0.07	-0.33	-0.07	0,66
Ozon	SL				
	0,36	0.10	-0.33	-0.10	0,33
N ₂ O	SL				
	0,5	0.17	0.33	0.44	1,33
H ₂ S	SL				
	0,03	0.20	-0.67	0.13	0,00
NH ₃	SL				
	0,03	0.10	-1.33	0.13	-1,00
Benzene	SL				
	1	0.13	-1.33	0.13	-0,33
Sum of negative deviations		-0,21	-11.99	-0.38	-7.00
Sum of positive deviations		2,16	2.00	1.97	2.98

The cross sensitivity fulfills the requirements. For the calculation of total uncertainty regarding VDI 4202 the greatest total cross sensitivity for each device has been used. This is - 11.99 µg/m³ for device 1 und -7.00 µg/m³ for device 2.

Cross-sensitivity examinations for the NO channel are in the EN 14211 required for the components CO₂, H₂O, ozone and NH₃. The results of the tests and the deviations of the measured signals with and without interfering component can be taken from Table 30.

Table 30: Cross-sensitivities Thermo 42i for the NO channel

Interferent		Analyser 1 (NO)		Analyser 2 (NO)	
		Deviation [ppb]		Deviation [ppb]	
		ZP	SP	ZP	SP
CO ₂	SL				
	500 µmol/mol	-0.10	-2.33	-0.10	-1.66
H ₂ O	SL				
	19 nmol/mol	0.83	-1.34	0.87	-1.00
Ozone	SL				
	200 nmol/mol	-0.07	-0.34	-0.20	-0.34
NH ₃	SL				
	200 nmol/mol	-0.04	-1.00	0.07	-1.00

The requirement according to EN 14211 allows an maximum deviation of 5 ppb for the components CO₂, NH₃, and H₂O a deviation of 2 ppb for the component ozone for the zero point as well as for the span point.

In Table 30 is to see, that these requirements are kept for both analysers.

6.5 Assessment

The cross-sensitivities of the measuring systems fulfill the minimum requirements. As to see in Table 30, the requirements of the EN 14211 are kept for H₂O, CO₂, NH₃ and ozone as well.

Minimum requirement fulfilled? yes

6.6 Documentation

The single values are given in Table 64 to Table 69 in the appendix.

6.1 5.2.12 Reproducibility R_D

The repeatability R_D of the measuring system shall be determined by parallel measurements with two identical measuring systems and shall be at least equal to 10. B_1 shall be used as the reference value.

EN 14211; 8.5.5: Standard deviation under field conditions $\leq 5\%$ of the average over 3 month for the component NO₂.

6.2 Equipment

Zero and Span Gases, data logger

6.3 Testing

In the lab test zero gas and test gas was offered the device by 10 turns in repetition. The concentration levels were applied in each case for 15 minutes. The last 5 minutes were recorded as a mean value and used for the further calculations.

For the calculation of the reproducibility R_D in the field the data were selected from a level of $60 \mu\text{g}/\text{m}^3 \pm 20\%$. Additionally the reproducibility R_D was calculated about all measured values in the field test. The evaluated data do not contain those one-hour mean values in which test gas applications were included.

6.4 Evaluation

The Table 35 shows the single values of the results achieved in the lab test. In Table 31 the statistical parameters of the evaluation are given.

For the calculation of total uncertainty regarding VDI 4202 the reproducibility R_D at B_1 has been used. The reproducibility R_D at B_1 is 23.

Table 31: Evaluation of the reproducibility R_D in the lab test NO₂

Reproducibility in the lab test				
No. of values	n	=	10	
Reference value	MBE	=	60	$\mu\text{g}/\text{m}^3$ (B_1)
t-value for the selected safety	t95	=	2.229	
Standard deviation out of parallel measurements	sd	=	0.748	
Reproducibility R_D	R(d)	=	36	
Mean value	Unit 1	=	60.22	$\mu\text{g}/\text{m}^3$
Mean value	Unit 2	=	60.70	$\mu\text{g}/\text{m}^3$

The following picture shows the evaluation of the reproducibility R_D in the field for the value pairs in the range of $B_1 \pm 20\%$:

Table 32: Evaluation of the reproducibility R_D near B_1 in the field test for NO₂

Reproducibility in the field test				
No. of values	n	=	368	
Reference value	MBE	=	60	µg/m ³ (B_1)
t-value for the selected safety	t ₉₅	=	1.966	
Standard deviation out of parallel measurements	sd	=	1.321	
Reproducibility R_D	R(d)	=	23	
Standard deviation	s	=	1.813	
Coefficient of correlation	r	=	0.9669	
Y = b* x + c Slope	b	=	1.009	
Intercept	c	=	-1.004	µg/m ³
Mean value	Unit 1	=	57.600	µg/m ³
Mean value	Unit 2	=	57.133	µg/m ³

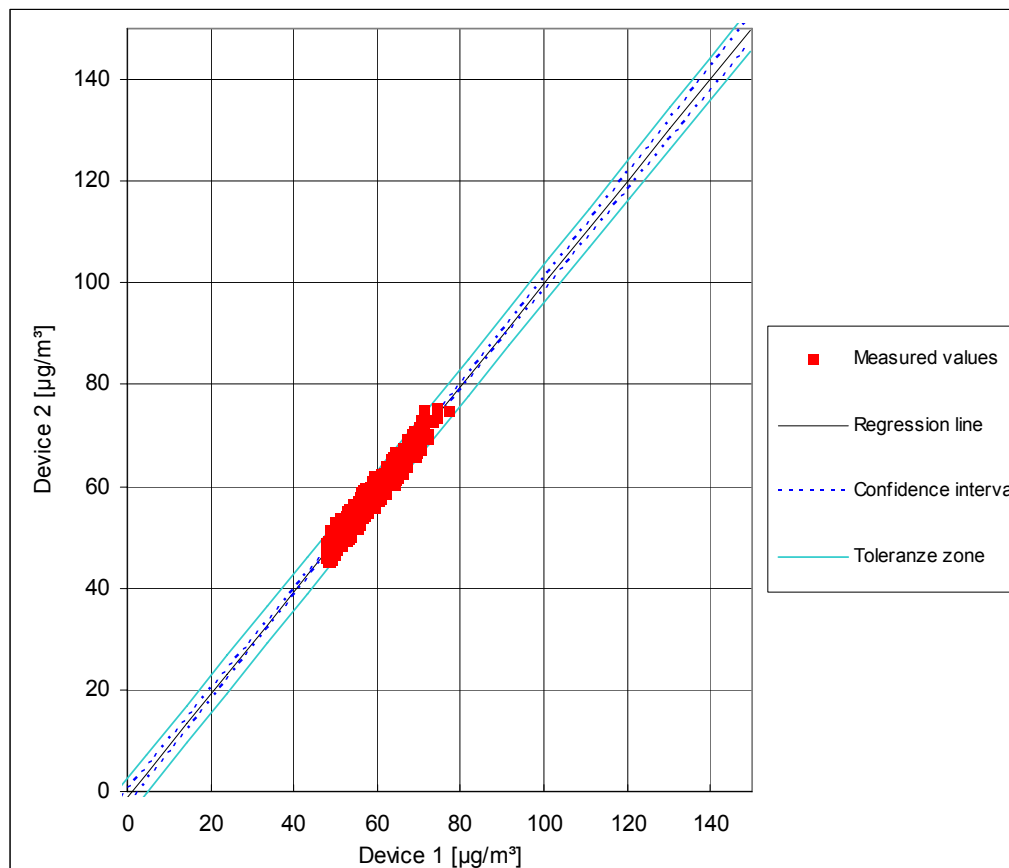


Figure 18: Graphics of the reproducibility R_D from the data near B_1 out of the field test for NO₂

Table 33: Evaluation of the reproducibility R_D of all data in the field test for NO₂

Reproducibility R_D in the field test				
No. of values	n	=	3168	
Reference value	MBE	=	60	µg/m ³ (B1)
t-value for the selected safety	t95	=	1.961	
Standard deviation out of parallel measurements	sd	=	1.177	
Reproducibility R_D	R(d)	=	26	
Standard deviation	s	=	1.648	
Coefficient of correlation	r	=	0.9982	
Y = b * x + c Slope	b	=	1.009	
Intercept	c	=	-0.283	µg/m ³
Mean value	Unit 1	=	30.548	µg/m ³
Mean value	Unit 2	=	30.536	µg/m ³

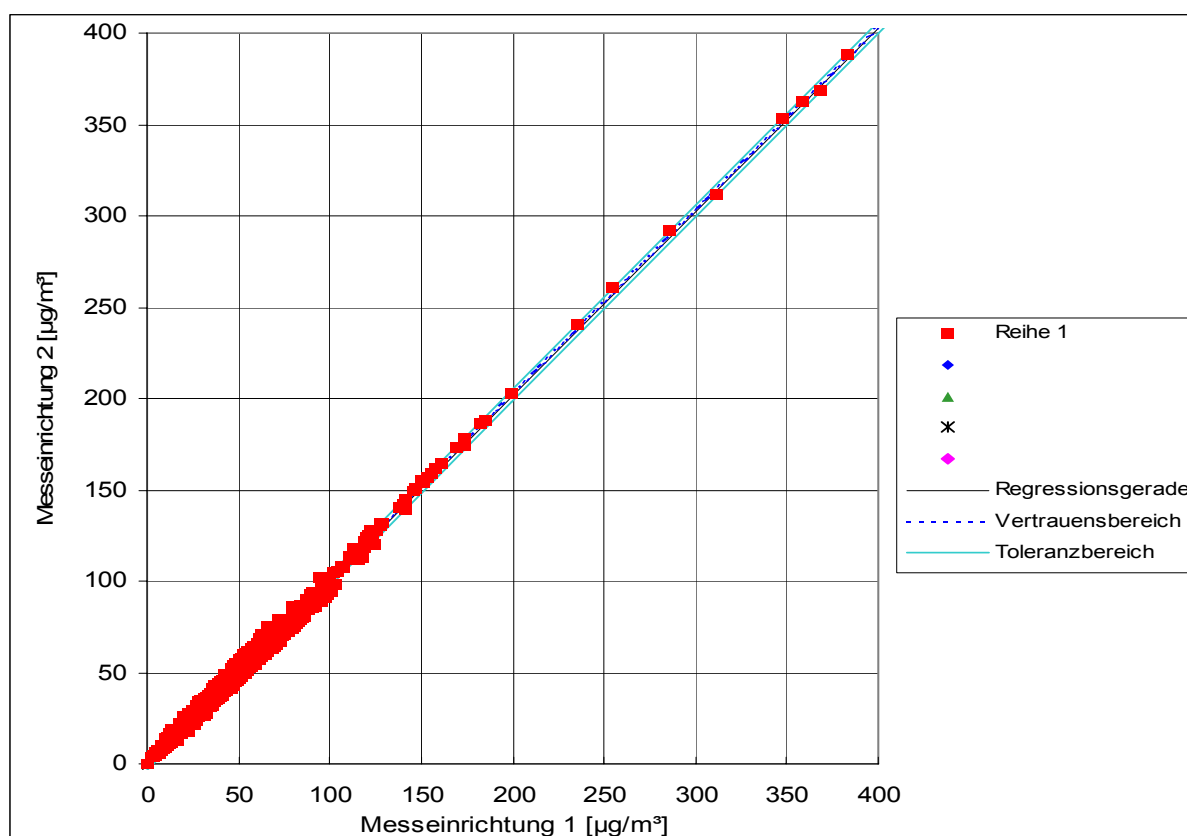

Figure 19: Graphics of the reproducibility R_D from all data out of the field for NO₂

Table 34: Evaluation of the reproducibility R_D of all data in the field test for NO

Reproducibility in the field test				
No. of values	n	=	3156	
Reference value	MBE	=	60	µg/m ³ (bezogen auf B1)
t-value for the selected safety	t95	=	1.961	
Standard deviation out of parallel measurements	sd	=	0.348	
Reproducibility R_D	R(d)	=	88	
Standard deviation	s	=	0.000	
Coefficient of correlation	r	=	1.0000	
Y = b * x + c Slope	b	=	0.984	
Intercept	c	=	0.000	µg/m ³
Mean value	Unit 1	=	11.507	µg/m ³
Mean value	Unit 2	=	11.326	µg/m ³

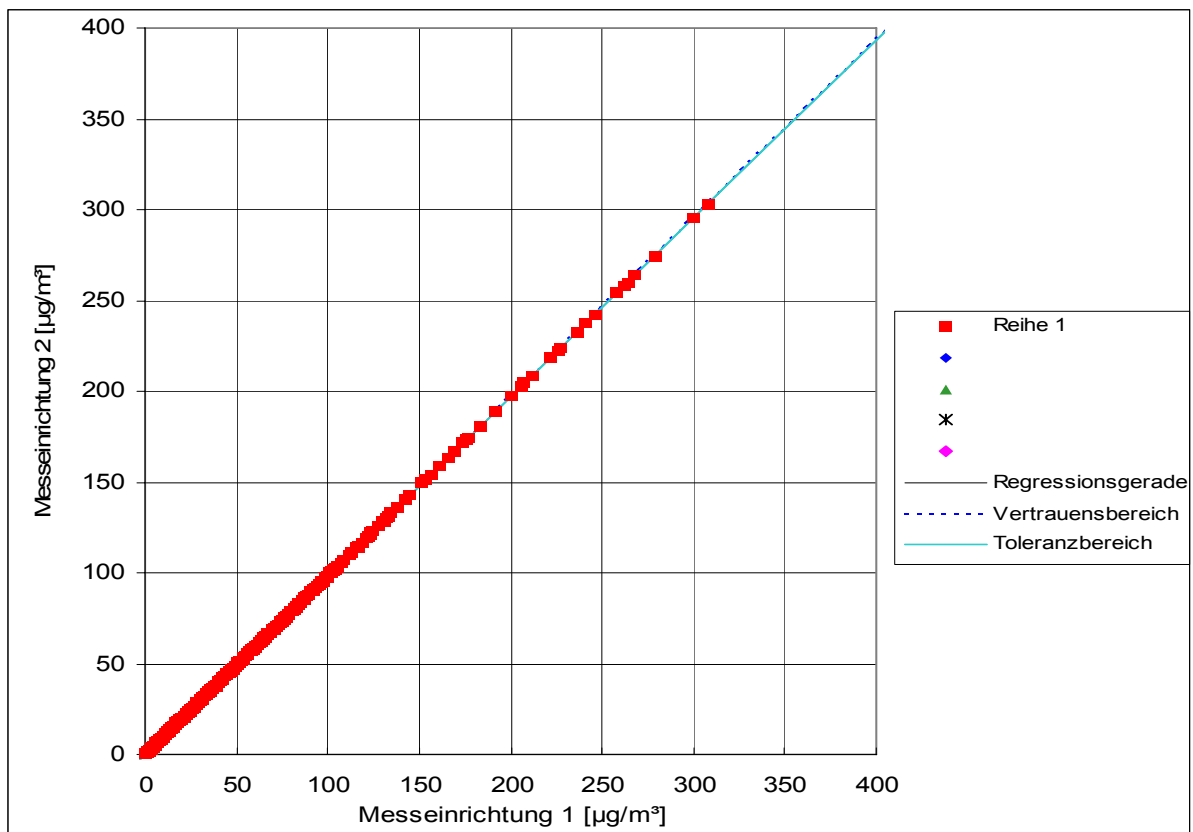


Figure 20: Graphics of the reproducibility R_D from all data out of the field for NO

The standard deviation under field conditions required in the EN 14211 is calculated as follows:

$$s_{r,f} = \frac{\left(\sqrt{\frac{\sum_{i=1}^n d_{f,i}^2}{2n}} \right)}{av} \times 100$$

where:

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

n is the number of parallel measurements

av is the average value during the field test

$d_{f,i}$ is the i-th difference of one parallel measurement

The standard deviation during the field test according to EN 14211 is calculated to 3.85 % about the mean value of all measured values. For that the field test data were corrected by the allowed drift. This value must be smaller or equal than the required service criterion of 5 % of the mean value about the measured value collective. Thus the standard deviation is kept under field conditions.

6.5 Assessment

The minimum value of 10 for the repeatability required by the VDI 4202 part 1 is exceeded clearly. Thus the minimum standards are kept. Also the standard deviation required for in the EN 14211 is kept.

Minimum requirement fulfilled? yes

6.6 Documentation

Table 35: Single values of the reproducibility in the lab

Single values of the reproducibility		
No.	Unit 1	Unit 2
1	55.95	55.87
2	56.36	58.49
3	57.92	59.31
4	51.48	51.54
5	59.84	59.99
6	62.52	63.25
7	67.23	67.71
8	65.52	66.59
9	65.11	63.51
10	60.29	60.77
X Mittel	60.22	60.70

6.1 5.2.13 Hourly averages

The measurement method shall allow for formation of hourly averages.

EN 14211; 8.5.12: The averaging effect must be $\leq 7\%$ of the measured value for the components NO and NO₂.

6.2 Equipment

A data logging system of the manufacturer Yokogawa with integration function, which can be programmed to an integration interval of one hour.

6.3 Testing

In the lab the formation of hour values was tested by connection of the data recording system with an integration time of an hour. During the field test the one-hour mean value formation was tested from the recorded minute integrals.

In addition the averaging effect according to EN 14211 has been tested.

6.4 Evaluation

The measuring equipment supplies measuring data continuously by an analogue or digital output. It was tested whether the data can be recorded with a suitable acquisition system and compacted to one-hour mean values. This was possible without problems.

The averaging effect has been calculated according to EN 14211:

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

with:

X_{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

The calculated averaging effect is -2.68 % for analyzer 1 and -1.10 % for analyzer 2. The calculated values are stated in Table 70 and Table 71.

6.5 Assessment

The measuring equipment allows the formation of one-hour mean values.

During the examination of the averaging effect according to EN 14211 no influence higher than 7% could be found.

Minimum requirement fulfilled? yes

6.6 Documentation

Here not essential.

6.1 5.2.14 Mains voltage and frequency

The change in the measured values at reference value B_1 caused by normal changes in the mains voltage in the interval $(230 +15/-20)$ V shall not exceed B_0 . In addition, for mobile applications the change in the measured value caused by changes in frequency of the mains voltage in the interval (50 ± 2) Hz shall not exceed B_0 .

EN 14211; 8.4.10: Sensitivity coefficient to electrical voltage $\leq 0,30$ nmol/mol/V (corresponds to 0,30 ppb/V or 0,375 $\mu\text{g}/\text{m}^3\text{V}$) for the component NO.

6.2 Equipment

Mains voltage: Transformer with a control range of 210 to 245 V

Mains frequency: Frequency modulator with a control range of 48 Hz to 52 Hz.

6.3 Testing

Mains voltage:

For the test of the influence of the mains voltage, a transformer was switched into the power supply of the measuring equipment. At the zero and reference point the change of the measured value was checked for a variation of the mains voltage between 210 V and 245 V and compared with the measuring signal at 230 V.

Mains frequency:

By switching a frequency-modulator into the current supply of the analysers the influence of the frequency change between 48 Hz and 52 Hz was compared with the measured value at 50 Hz.

6.4 Evaluation

For the variation of the mains voltage the following results have been found at the zero point:

Table 36: Variation of mains voltage at the zero point (NO₂)

Unit No. 1			Deviation		Deviation
Measurement	230 V	210 V	210 V to 230 V	245 V	245 V to 230 V
	$[\mu\text{g}/\text{m}^3]$	$[\mu\text{g}/\text{m}^3]$	$[\mu\text{g}/\text{m}^3]$	$[\mu\text{g}/\text{m}^3]$	$[\mu\text{g}/\text{m}^3]$
1	0.38	0.57	0.19	0.76	0.38
2	0.57	0.76	0.19	0.57	0.00
3	0.38	0.38	0.00	0.57	0.19

Unit No. 2			Derviation		Deviation
Measurement	230 V	210 V	210 V to 230 V	245 V	245 V to 230 V
	$[\mu\text{g}/\text{m}^3]$	$[\mu\text{g}/\text{m}^3]$	$[\mu\text{g}/\text{m}^3]$	$[\mu\text{g}/\text{m}^3]$	$[\mu\text{g}/\text{m}^3]$
1	0.19	0.57	0.38	0.96	0.77
2	0.76	0.57	-0.19	0.57	-0.19
3	0.38	0.76	0.38	0.76	0.38

In comparison to the B_0 value of nitrogen dioxide, which is $3 \mu\text{g}/\text{m}^3$, are all deviations at the zero point during the variation of the mains voltage in the limits of the requirements.

For the variation of the mains voltage the following results have been found at the zero point:

Table 37: Variation of mains voltage at the span point (NO₂)

Unit No. 1			Deviation		Deviation
Measurement	230 V	210 V	210 V to 230 V	245 V	245 V to 230 V
	$[\mu\text{g}/\text{m}^3]$	$[\mu\text{g}/\text{m}^3]$	$[\mu\text{g}/\text{m}^3]$	$[\mu\text{g}/\text{m}^3]$	$[\mu\text{g}/\text{m}^3]$
1	368.63	369.20	0.57	370.73	2.10
2	371.11	370.54	-0.57	371.50	0.39
3	370.35	371.11	0.76	371.11	0.76

Unit No. 2			Deviation		Deviation
Measurement	230 V	210 V	210 V to 230 V	245 V	245 V to 230 V
	$[\mu\text{g}/\text{m}^3]$	$[\mu\text{g}/\text{m}^3]$	$[\mu\text{g}/\text{m}^3]$	$[\mu\text{g}/\text{m}^3]$	$[\mu\text{g}/\text{m}^3]$
1	366.53	368.82	2.29	368.63	2.10
2	367.29	368.44	1.15	368.63	1.34
3	367.48	368.06	0.58	369.01	1.53

In comparison to the B_0 value of nitrogen dioxide, which is $3 \mu\text{g}/\text{m}^3$, are all deviations at the span point during the variation of the mains voltage in the limits of the requirements.

The greatest deviation of both devices $2.10 \mu\text{g}/\text{m}^3$ for device 1 and $2.29 \mu\text{g}/\text{m}^3$ for device 2 have been taken for the calculation of total uncertainty of VDI 4202.

In the EN 14211 a test of the mains voltage for NO is also required. The allowed deviation is 0.3 ppb per Volt. This means for a variation between 210 V and 230 V an allowed deviation of 6 ppb ($7.5 \mu\text{g}/\text{m}^3$) and between 230 V and 245 V an deviation of maximum 4.5 ppb ($5.63 \mu\text{g}/\text{m}^3$).

The sensitivity coefficient of the voltage influence according to EN 14211 is calculated described in the following:

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

where:

b_v is the voltage influence

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

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

V_1 is the minimum voltage V_{\min}

V_2 is the maximum voltage V_{\max}

The data of the examinations are in the following table to see:

Table 38: Variation of mains voltage at the zero point (NO)

Unit No. 1			Deviation		Deviation
Measurement	230 V	210 V	210 V to 230 V	245 V	245 V to 230 V
	[µg/m ³]	[µg/m ³]	[µg/m ³]	[µg/m ³]	[µg/m ³]
1	0.30	0.20	-0.10	0.40	0.10
2	0.00	0.10	0.10	0.30	0.30
3	0.20	0.10	-0.10	0.10	-0.10
Average	0.17	0.13		0.27	

Unit No. 2			Deviation		Deviation
Measurement	230 V	210 V	210 V to 230 V	245 V	245 V to 230 V
	[µg/m ³]	[µg/m ³]	[µg/m ³]	[µg/m ³]	[µg/m ³]
1	0.20	0.10	-0.10	0.10	-0.10
2	0.20	0.10	-0.10	0.20	0.00
3	0.00	0.00	0.00	0.10	0.10
Average	0.13	0.07		0.13	

Table 39: Variation of mains voltage at the span point (NO)

Unit No. 1			Deviation		Deviation
Measurement	230 V	210 V	210 V to 230 V	245 V	245 V to 230 V
	[µg/m ³]	[µg/m ³]	[µg/m ³]	[µg/m ³]	[µg/m ³]
1	649.50	650.20	0.70	650.30	0.80
2	649.30	650.10	0.80	650.20	0.90
3	649.70	650.40	0.70	650.30	0.60
Average	649.50	650.23		650.27	

Unit No. 2			Deviation		Deviation
Measurement	230 V	210 V	210 V to 230 V	245 V	245 V to 230 V
	[µg/m ³]	[µg/m ³]	[µg/m ³]	[µg/m ³]	[µg/m ³]
1	651.40	652.20	0.80	652.00	0.60
2	651.10	651.80	0.70	651.60	0.50
3	650.80	651.90	1.10	651.80	1.00
Average	651.10	651.93		651.80	

The sensitivity coefficient to electrical voltage is:

Device 1 ZP: 0.01 (µg/m³)/V equal to -0.008 (nmol/nmol/V)

Device 2: ZP -0.01 (µg/m³)/V equal to -0.008 (nmol/nmol/V)

Device 1: SP 0.05 (µg/m³)/V equal to 0.04 (nmol/nmol/V)

Device 2: SP 0.05 (µg/m³)/V equal to 0.04 (nmol/nmol/V)

Both analysers fulfill the requirements for the variation of the mains voltage for the component NO.

The mean values and the deviations in the frequency interval from 48 Hz to 52 Hz at the zero and reference point are to be taken from Table 40.

These dates are only for information. For the decelerated scope of suitability “stationary operation” are no requirements for the mains frequency in the guidelines.

Table 40: Variation of mains frequency

Zero level				
Frequency	Average			Deviation
Measurement	48 Hz	50 Hz	52 Hz	48 Hz - 50 Hz
Cannel	[ppb]	[ppb]	[ppb]	[ppb]
NO	-0.40	-0.17	-0.57	-0.17
NO ₂	0.33	0.40	0.33	0.00
NO _x	-0.07	0.23	-0.23	-0.17

Span level NO ₂				
Frequency	Average			Deviation
Measurement	48 Hz	50 Hz	52 Hz	48 Hz - 50 Hz
Cannel	[ppb]	[ppb]	[ppb]	[ppb]
NO	-0.10	-0.10	-0.10	0.00
NO ₂	149.87	151.67	154.40	4.53
NO _x	149.77	151.57	154.30	4.53

Span level NO				
Frequency	Average			Deviation
Measurement	48 Hz	50 Hz	52 Hz	48 Hz - 50 Hz
Cannel	[ppb]	[ppb]	[ppb]	[ppb]
NO	199.00	202.33	207.00	8.00
NO ₂	8.33	7.67	7.33	-1.00
NO _x	207.33	210.33	214.33	7.00

6.5 Assessment

The measuring system fulfils the minimum requirements regarding the variations of the mains voltage.

Minimum requirement fulfilled? yes

6.6 Documentation

Here not essential.

6.1 5.2.15 Failure in the mains voltage

In case of malfunction of the measuring system or failure in the mains voltage, uncontrolled emission of operating and calibrating gas shall be avoided. The instrument 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

No additional devices.

6.3 Testing

A power failure was simulated by separation of the power plug during the measuring operation. Longer interruptions of the voltage supply (72 h) were carried out additionally at several site alternations. After each restart the measuring system was checked for the correct operation mode.

6.4 Evaluation

When mains voltage returns, the analyser works after the warm up time in a correct way. The programmed parameters, especially the calibrating data are still secured after a power failure and the analyser is ready for measurement.

If gases are connected uncontrolled emissions of operating and calibrating gas after a malfunction of the power supply were not detected.

6.5 Assessment

The minimum requirements are kept during a power breakdown. The operability of the analyser is safeguarded and calibrating gas does not exhaust.

Minimum requirement fulfilled? yes

6.6 Documentation

Here not essential.

6.1 5.2.16 Operating states

Measuring systems shall be able to telemetrically transmit important operating states by status signals.

6.2 Equipment

In addition to the measuring systems a computer has been used to control the instruments.

6.3 Testing

The analysers have been connected by a data logging system and a network to an external computer in order to control the analyser. Afterwards different operating states were simulated (readiness for operation, maintenance, and malfunction) and recorded by means of data transmission.

6.4 Evaluation

The model 42i can be integrated and remotely operated by a modem and/or the available interfaces in a network.

Both RS 232/RS 485 communication as well as an Ethernet-communication between a computer or between several analysers are possible.

Status signals about the operating state of the measuring system as well as measured data can be sent telemetrically over the available interfaces. In addition to the analogous communication the above described digital data buses are available.

During the tests the status signals were recorded by the downstream data logging system correctly.

To further communication options and technical details the manual is referred to at this place.

6.5 Assessment

The essential operating states are controllable via telemetric status signals.

Minimum requirement fulfilled? yes

6.6 Documentation

Here not essential.

6.1 5.2.17 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

In addition to the measuring systems a computer has been used to control the instruments.

6.3 Testing

The analysers have been connected by a data logging system and a network to an external computer in order to control the analyser. With this external computer a functional check of the analyser has been performed. Afterwards a calibration was activated by the network.

6.4 Evaluation

The switch-over between measure- and calibrating-mode occurred automatically both during the excitation of the analyser front as also computer-assisted. In addition to the status signals send the mode of operation is readable at the device display.

6.5 Assessment

The switch-over between the modes of operation is manual and telemetric possible.

Minimum requirement fulfilled? yes

6.6 Documentation

Here not essential.

6.1 5.2.18 Availability

The availability of the measuring system shall be at least 90 %.

EN 14211; 5.8.7: Availability of the measuring system for the component > 90 %.

6.2 Equipment

No additional devices.

6.3 Testing

The total operating time is calculated from the start- and final-time. The other periods of time are taken from the documentation of the test .

6.4 Evaluation

The percentile availability is calculated as follows:

Equation 1: Calculation of the availability

$$V = \frac{t_E - (t_K + t_A + t_W)}{t_E} * 100\%$$

The periods of time for the determination of the availability for both analysers are to be seen in Table 41:

Table 41: Availability Thermo 42i

			Unit 1	Unit 2
Operating time	t_E	h	3168	3168
Calibration time	t_K	h	132	132
Outage time	t_A	h	0	0
Maintenance time	t_W	h	4	4
Availability	V	%	96	96

The calibrating-times result from the daily test gas tasks for the determination of the drift behaviour and the maintenance interval. There were no device-caused outage times with both analysers during the whole field test. The maintenance time results from the times which were needed for the replacement of the Teflon filters contained in the sample gas manifold.

According to EN 14211 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 (three months) minus the time for regular calibration, conditioning and maintenance of the instrumentation

With the values of Table 41 the availability is calculated to 96 %.

6.5 Assessment

The availability is higher than 90 %, so that the minimum requirement is fulfilled . The performance criteria according to EN 14211 are fulfilled by an availability of 96 %.

Minimum requirement fulfilled? yes

6.6 Documentation

Here not essential.

6.1 5.2.19 Efficiency of the converter

In case of measuring systems with a converter, the efficiency of the converter shall be at least 95 %.

EN 14211; 8.4.14: Efficiency of the converter ≥ 98 %

6.2 Equipment

Zero gas, NO gas, ozone generator.

6.3 Testing

By the method of gas phase titration according to VDI 2453 part 2 the converter efficiency has been determined. The converter efficiency has been determined by putting on a NO test gas and a mixture of NO and ozone gas in an alternating way to the analysers.

6.4 Evaluation

By order of both test gas points, the following converter efficiencies have been calculated in the lab.

Table 42: Efficiency of the converter Thermo 42i lab test

Analyser 1	Cannel	NO test gas	NO test gas with ozone	Efficiency
		[ppb]	[ppb]	[%]
	NO	554	170	
	NO ₂	12	386	
	NO _x	566	555	97
Analyser 2	Cannel	NO test gas	NO test gas with ozone	Efficiency
		[ppb]	[ppb]	[%]
	NO	543	165	
	NO ₂	10	376	
	NO _x	553	541	97

At the end of the field test, the analysers had the converter efficiency:

Table 43: Efficiency of the converter Thermo 42i field test

Analyser 1	Cannel	NO test gas	NO test gas with ozone	Efficiency
		[ppb]	[ppb]	[%]
	NO	554	166	
	NO ₂	7	390	
	NO _x	561	556	99
Analyser 2	Cannel	NO test gas	NO test gas with ozone	Efficiency
		[ppb]	[ppb]	[%]
	NO	541	161	
	NO ₂	7	380	
	NO _x	547	541	99

The average converter efficiency is 98 % for both devices.

6.5 Assessment

The efficiency of the converter is for both analysers higher than the required 95 %. The according to EN 14211 required efficiency of the converter 98 % is also fulfilled.

Minimum requirement fulfilled? yes

6.6 Documentation

Here not essential.

6.1 5.2.20 Maintenance interval

The maintenance interval of the measuring system shall be determined and specified. The maintenance interval should be 28 days, if possible, but at least 14 days.

EN 14211: 8.5.6 Maintenance interval minimum 14 days

6.2 Equipment

Test standards for determination of the drift behaviour.

6.3 Testing

Within the framework of the examination is to be investigated which maintenance operations in which intervals are necessary for the perfect effectiveness of the measuring system. As far as no extensive maintenance operations are necessary physically in shorter intervals, the maintenance interval basically results from the drift behaviour of the measuring equipment.

6.4 Evaluation

Like to see in chapter 5.2.9 und 5.2.10, the drift of the measured value has in comparison to the zero point drift the greatest influence of the determination of the maintenance interval.

For the drift of the NO₂ value and the calibration work the following theoretic periods of time results. The periods are calculated from the regression of the drift of the measured value.

	Daily drift [mg/(m ³ *d)]	Interval [Days]
Unit 1	0.034	88
Unit 2	0.003	1000

The number of the days results from the permissible drift in the maintenance interval of 3 µg/m³ divided by the drift determined daily.

Besides the drift additional maintenance operations influence the duration of the maintenance interval, which at the Thermo 42i devices are limited to the replacement of sample inlet Teflon filter at the analyser entry in the incoming. The filters were replaced during the field test monthly.

Only from the results of the drift investigations the measuring system has reached a maintenance interval of at least 88 days. As a precaution the dust filter contained in the sample inlet should be exchanged every 4 weeks. The necessary interval is to be determined finally site-specific

So the measuring systems could show, that in an three month maintenance interval no further maintenance work is necessary.

As a result of the requirements in the guideline VDI 4203 part 3 it is allowed to concede a maintenance interval of only 4 weeks to the analysers, if the systems have attended a 3 month field test, also in the case that there is no service work necessary

In the EN 14211 are existing comparable requirements. For the use according to this guideline the maintenance interval for the NO channel must be determined. Within the scope of the tests the maintenance interval was calculated with minimum three month.

6.5 Assessment

The minimum requirements are fulfilled. The maintenance value is one month. According to EN 14211 the maintenance interval for the NO channel is more than 3 month.

Minimum requirement fulfilled? yes

6.6 Documentation

Here not necessary.

6.1 5.2.21 Overall uncertainty

The expanded uncertainty of the measuring system shall be determined. The value determined shall not exceed the corresponding data quality objectives in the EU Daughter Directives on air quality.

6.2 Equipment

No further equipment necessary.

6.3 Testing

Calculation of the expanded uncertainty out of the data from the tests.

6.4 Evaluation

The determination of the expanded uncertainty u_M of the measured values from the measuring system done according to appendix C of the VDI 4203 part 1 from the uncertainty contributions u_k of the relevant procedure characteristics.

Table 44: Expanded uncertainty for single values, device 1, reference value 200 $\mu\text{g}/\text{m}^3$

Performance characteristic Device 1	Requirement	Result		Uncertainty u	Squared uncertainty u^2
				$\mu\text{g}/\text{m}^3$	$(\mu\text{g}/\text{m}^3)^2$
Reproducibility	10	23		1.30	1.70
Linearity	4 $\mu\text{g}/\text{m}^3$	-3.00	$\mu\text{g}/\text{m}^3$	-1.73	3.00
Temperature dependence at zero	3 $\mu\text{g}/\text{m}^3$	2.5	$\mu\text{g}/\text{m}^3$	1.42	2.02
Temperature dependence at span	3 % von B_1	1.9	$\mu\text{g}/\text{m}^3$	1.12	1.25
Drift at zero	3 $\mu\text{g}/\text{m}^3$	-0.039	$\mu\text{g}/\text{m}^3$	-0.02	0.00
Drift at span	3 % von B_1	1.023	$\mu\text{g}/\text{m}^3$	0.59	0.35
Mains voltage	3 $\mu\text{g}/\text{m}^3$	2.1	$\mu\text{g}/\text{m}^3$	1.21	1.47
Cross-sensitivities	12 $\mu\text{g}/\text{m}^3$	-12.0	$\mu\text{g}/\text{m}^3$	-6.92	47.92
Uncertainty of test gas	4 $\mu\text{g}/\text{m}^3$	4.0	$\mu\text{g}/\text{m}^3$	4.00	16.00
				Σu^2	73.71
				$U(c) = 2u(c)$	17.17
				$U(c) / \text{Reference}$	8.59

Table 45: Expanded uncertainty for single values, device 2, reference value 200 $\mu\text{g}/\text{m}^3$

Performance characteristic Device 2	Requirement	Result		Uncertainty u	Squared uncertainty u^2
				$\mu\text{g}/\text{m}^3$	$(\mu\text{g}/\text{m}^3)^2$
Reproducibility	10	23		1.30	1.70
Linearity	4 $\mu\text{g}/\text{m}^3$	2.40	$\mu\text{g}/\text{m}^3$	1.39	1.92
Temperature dependence at zero	3 $\mu\text{g}/\text{m}^3$	2.9	$\mu\text{g}/\text{m}^3$	1.67	2.80
Temperature dependence at span	3 % von B_1	-1.4	$\mu\text{g}/\text{m}^3$	-0.80	0.64
Drift at zero	3 $\mu\text{g}/\text{m}^3$	-0.009	$\mu\text{g}/\text{m}^3$	-0.01	0.00
Drift at span	3 % von B_1	0.090	$\mu\text{g}/\text{m}^3$	0.05	0.00
Mains voltage	3 $\mu\text{g}/\text{m}^3$	2.3	$\mu\text{g}/\text{m}^3$	1.32	1.75
Cross-sensitivities	12 $\mu\text{g}/\text{m}^3$	-7.0	$\mu\text{g}/\text{m}^3$	-4.04	16.33
Uncertainty of test gas	4 $\mu\text{g}/\text{m}^3$	4.0	$\mu\text{g}/\text{m}^3$	4.00	16.00
				Σu^2	41.15
				$U(c) = 2u(c)$	12.83
				$U(c) / \text{Reference}$	6.42

Table 46: Expanded uncertainty for average values, device 1, reference value 40 µg/m³

Performance characteristic Device 1	Uncertainty (single value)	Time Base	Number nk	Square pf Uncertainty (average)
				(µg/m ³) ²
Reproducibility	1.30	1 hour	7884	0.000
Linearity	-1.73	1 year	1	3.000
Temperature dependence at zero	1.42	1 year	1	2.017
Temperature dependence at span	1.12	1 year	1	1.255
Drift at zero	-0.02	4 weeks	13	0.000
Drift at span	0.59	4 weeks	13	0.027
Mains voltage	1.21	1 year	1	1.470
Cross-sensitivities	-6.92	3 month	4	11.980
				$\sum u_m^2(c_k)$
				19.749
				$U(\bar{c}) = 2u(\bar{c})$
				8.89
				$\frac{U(\bar{c})}{\text{Reference}}$
				22.22

Table 47: Expanded uncertainty for average values, device 2, reference value 40 µg/m³

Performance characteristic Device 2	Uncertainty (single value)	Time Base	Number nk	Square pf Uncertainty (average)
				(µg/m ³) ²
Reproducibility	1.30	1 hour	7884	0.000
Linearity	1.39	1 year	1	1.920
Temperature dependence at zero	1.67	1 year	1	2.803
Temperature dependence at span	-0.80	1 year	1	0.644
Drift at zero	-0.01	4 weeks	26	0.000
Drift at span	0.05	4 weeks	26	0.000
Mains voltage	1.32	1 year	1	1.748
Cross-sensitivities	-4.04	3 month	4	4.083
				$\sum u_m^2(c_k)$
				11.199
				$U(\bar{c}) = 2u(\bar{c})$
				6.69
				$\frac{U(\bar{c})}{\text{Reference}}$
				16.73

For the calculation of the expanded measurement uncertainties, the single results of the respective test points have been evaluated in summary. As far as there are several independent results from single investigations available, the respective adverse value was used.

The expanded uncertainties are 8.59 % respectively 6.42 % for $U(c)$ and 22.22 % respectively 16.73 % for $U(\bar{c})$.

The required measurement uncertainty for the average values ($U(\bar{c})$) of at maximum 15 % has not been fulfilled by both devices. Under the given circumstances (reference value of 40 µg/m³), the measurement uncertainty for the average values cannot be kept. In the revision of VDI 4203 Sheet 3 (Draft 04 of 30.05.2007), this evaluation is completely rejected.

6.5 Assessment

The measuring system falls below the required expanded uncertainty of 15 % clearly by a result of 8.59 %.

Minimum requirement fulfilled? yes

6.6 Documentation

Here not necessary.

6.1 5.4 Requirements on multiple-component measuring systems

Multiple-component measuring systems shall comply with the requirements set for each component, also in case of simultaneous operation of all measuring channels.

6.2 Equipment

not applicable

6.3 Testing

not applicable

6.4 Evaluation

not applicable

6.5 Assessment

Not applicable.

Minimum requirement fulfilled? not applicable

6.6 Documentation

Here not essential.

7 Further test points according to EN 14211

7.1.1 7.1 Sensitivity coefficient to sample gas pressure

EN 14211; 8.4.7: The sensitivity coefficient to sample gas pressure for NO must be smaller than $\leq 8.0 \text{ nmol/mol/kPa}$ (corresponds to 8 ppb/kPa or $10 \text{ }\mu\text{g/m}^3\cdot\text{kPa}$).

7.2 Equipment

Zero gas, span gas, mass-flow-controller and unit to measure the sample gas pressure

7.3 Testing

The measurements have been done at a concentration of about 70 % to 80 % of the maximum of the CO certification range at pressures of $80 \text{ kPa} \pm 0.2 \text{ kPa}$ and $110 \text{ kPa} \pm 2 \text{ kPa}$. At every pressure three single measurements are to be carried out after a space of time which corresponds to an independent measurement. The mean values of these measurements at all pressures are calculated.

The volume flow of the test gas system was chosen higher for the generation of the overpressure than the volume flow sucked by the analysers. The bypass in the incoming line to the analysers was closed to reach the necessary overpressure. The low air pressure was made by the analyser pump itself when the bypass was closed and the test gas flow was reduced synchronously.

7.4 Evaluation

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

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

where:

b_{sp} is the sample gas pressure influence

C_{P1} is the average of the measurements at sample gas pressure P_1

C_{P2} is the average of the measurements at sample gas pressure P_2

P_1 is the sample gas pressure P_1

P_2 is the sample gas pressure P_2

The determined sensitivity coefficient of the sample gas pressure according to EN 14211 b_{gp} is 0.07 ppb/kPa for device 1 and 0.08 ppb/kPa for device 2. This value must be compared with the in the guidelines required value of 8 ppb/kPa. The minimum requirement is kept.

7.5 Assessment

The sensitivity coefficient to sample gas pressure keeps the requirements of the EN 14211.

7.6 Documentation

Table 48: *Test results of the variation of the sample gas pressure for the component NO*

Unit 1				
Sample gas pressure	1. Rep.	2. Rep.	3. Rep.	Average
[kPa]	[ppb]	[ppb]	[ppb]	[ppb]
ca. 80.0	200	200	201	200.33
99.8	199	200	200	199.67
ca. 110.0	198	197	200	198.33
Difference 80.0 hPa and 110.0 hPa:				2.00

Unit 2				
Sample gas pressure	1. Rep.	2. Rep.	3. Rep.	Average
[kPa]	[ppb]	[ppb]	[ppb]	[ppb]
ca. 80.0	199	198	198	198.33
99.8	199	199	200	199.33
ca. 110.0	197	196	195	196.00
Difference 80.0 kPa and 110.0 kPa:				2.33

7.1.2 7.1 Sensitivity coefficient to sample gas temperature

EN 14211; 8.4.8: The sensitivity coefficient to sample gas temperature for NO should be smaller than $\leq 3.0 \text{ nmol/mol/K}$ (corresponds to 3 ppb/K $3.75 \text{ µg/m}^3\text{K}$).

7.2 Equipment

Climate chamber, zero- and span gas.

7.3 Testing

The examination was made parallel to the checkpoint 8.4.9 sensitivity coefficient of the ambient temperature. By the choice of the tubing length in the climate chamber it was secured that the temperature of the test gas reached the required temperatures between 0°C and 30°C when entering the inlet of the analyser.

7.4 Evaluation

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

$$b_{gt} = \frac{(C_{T2} - C_{T1})}{(T_2 - T_1)}$$

where:

b_{gt} is the sample gas temperature influence

C_{T1} is the average concentration of the measurements at sample gas temperature T_1

C_{T2} the average concentration of the measurements at sample gas temperature T_2

T_1 is the sample gas temperature T_1

T_2 is the sample gas temperature T_2

The sensitivity coefficient to sample gas temperature is at the zero point:

Unit 1: 0.01 (nmol/mol/K)

Unit 2: 0.07 (nmol/mol/K)

The sensitivity coefficient to sample gas temperature is at the span point:

Unit 1: -0.31 (nmol/mol/K)

Unit 2: 0.30 (nmol/mol/K)

During the tests there could no significant influence of the sample gas temperature to the measuring signal in the temperature range of 0 °C to 30 °C be found.

7.5 Assessment

The minimum requirements are kept.

7.6 Documentation

Here not essential.

7.1.3 7.1 Short-term drift at zero

EN 14211; 8.4.4: The short-term drift at zero for the component NO must be smaller than ≤ 2.0 nmol/mol over a period of 12 hours (corresponds to 2 ppb or 2.5 $\mu\text{g}/\text{m}^3$).

7.2 Equipment

Synthetic air for zero point check.

7.3 Testing

Following the EN 14211 the short-term drift is to be determined in the lab with in each case 20 single measurements before and after a 12 h duration of time. The determined short-term drift is smaller than the allowed drift of 2 ppb.

7.4 Evaluation

Short term drift at zero level:

$$D_{s,z} = (C_{z,2} - C_{z,1})$$

In this case is:

$D_{s,z}$ the 12-hour-drift at zero level (mg/m^3)

$C_{z,1}$ the mean of the zero gas measurement at the beginning of the drift period ($\mu\text{g}/\text{m}^3$)

$C_{z,2}$ the mean of the zero gas measurement at the end of the drift period ($\mu\text{g}/\text{m}^3$)

The following short-term drifts are resulting at the zero level:

Unit 1: -0.4 ($\mu\text{g}/\text{m}^3$)/12 h equal to 0.32 ppb/12h

Unit 2: -0.5 ($\mu\text{g}/\text{m}^3$)/12 h equal to 0.40 ppb/12h

7.5 Assessment

The measuring system fulfils the short-term drift criterion at the zero level of the EN 14211.

7.6 Documentation

Here not essential.

7.1.4 7.1 Short-term drift at span level

EN 14211; 8.4.4: The short-term drift for the component NO at span level must be smaller than $\leq 6,0$ nmol/mol over a period of 12 hours (corresponds to 6 ppb or $7.5 \mu\text{g}/\text{m}^3$).

7.2 Equipment

NO test gas for the span point check.

7.3 Testing

Following the EN 14211 the short-term drift is to be determined in the lab with in each case 20 single measurements before and after a 12 h duration of time. The determined short-term drift is smaller than the allowed drift of 6 ppb.

7.4 Evaluation

Short term drift at span level:

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

In this case is:

$D_{S,S}$ the 12-hour-drift at span level (mg/m^3)

$C_{S,1}$ the mean of the zero gas measurement at the beginning of the drift period ($\mu\text{g}/\text{m}^3$)

$C_{S,2}$ the mean of the zero gas measurement at the end of the drift period ($\mu\text{g}/\text{m}^3$)

The following short-term drifts are resulting at the span level:

Unit 1: $0.2 (\mu\text{g}/\text{m}^3)/12 \text{ h}$ equal to $0.16 \text{ ppb}/12\text{h}$

Unit 2: $0.6 (\mu\text{g}/\text{m}^3)/12 \text{ h}$ equal to $0.48 \text{ ppb}/12\text{h}$

7.5 Assessment

The measuring system fulfils the short-term drift criterion at the span level of the EN 14211.

7.6 Documentation

Here not essential.

7.2 Appendix A (normative) Calculation residence times for a maximum allowable NO₂ increase in the sampling line [ISO 13964]

The increase of the sampled nitrogen dioxide (NO₂) is due the effect of the reaction of ambient ozone (O₃) with nitric oxide in the sampling line.

The allowed increase of the NO₂ according to EN 14211 is maximum 4 nmol/mol.

7.2 Equipment

Ozone generator.

7.3 Testing

After the determination of the residence time of the sample gas in the sampling line, test gas was offered to the analysers. By means of an ozone analyser, the ozone concentration in the test gas has been determined.

7.4 Evaluation

By means of the following formulas the influence of the residence time on the increase of NO₂ in the sampling line can be determined:

Equation 2: Calculation of the increase of the NO₂ in the sampling

$$[O_3]_0 = \frac{b \times [O_3]_t}{[O_3]_t - [NO]_t \times e^{(b \times k \times t)}}$$

with:

[O₃]₀ is the ozone concentration at the sampling inlet

[O₃]_t is the ozone concentration after t seconds of residence time in the sampling line

[NO]_t is the nitric oxide concentration after t seconds of residence time in the sampling line

b is the concentration difference between [O₃]_t and [NO]_t with b ≠ 0

$$b = [O_3]_t - [NO]_t$$

k is the constant for the reaction of O₃ with NO

$$k = 4.43 \times 10^{-4} \text{ nmol/mol}^{-1} \text{ s}^{-1} \text{ bei } 298 \text{ K}$$

t is the residence time in seconds

The increase of NO₂ from the reaction of ozone and nitric oxide is calculated from the loss of ozone:

$$NO_2 = [O_3]_0 - [O_3]_t$$

The tested measuring system shows the following result:

$$\begin{aligned} [\text{O}_3]_t &= 22 \text{ nmol/mol} \\ [\text{NO}]_t &= 100 \text{ nmol/mol} \\ b &= -78 \text{ nmol/mol} \\ k &= 4.43 \times 10^{-4} \text{ nmol/mol}^{-1} \text{ s}^{-1} \text{ at } 298 \text{ K} \\ t &= 2.1 \text{ s (calculated from 1 m sampling line with a diameter of 6 mm a analyser sample flow of 0.8 l/min)} \end{aligned}$$

The calculated increase of the NO₂ concentration affected by the presence of ozone is 2.2 nmol/mol NO₂ (corresponds to an decrease of the NO concentration of 2.2 nmol/mol) and is deeper than the allowed increment of 4 nmol/mol.

7.5 Assessment

The measuring system fulfils the requirements of the EN 14211.

7.6 Documentation

Here not essential.

7.2.1 7.1 Difference sample/calibration port

EN 14211; 8.4.13: Difference sample/calibration port $\leq 1,0 \%$

7.2 Equipment

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 followed by two individual measurements. After a period of at least 4 response times the test shall be repeated using the calibration port. The difference shall be calculated according to:

$$D_{SC} = \frac{x_s - x_c}{c_t} \times 100$$

with

D_{SC} the difference sample/calibration port (%)

x_s the average of the measured concentrations using the sample port

x_c the average of the measured concentrations using the calibration port

c_t the concentration of the test gas

D_{SC} shall comply with the performance criterion.

7.3 Testing

The test gas is offered like described above in an alternating way to the sample and calibration port.

7.4 Evaluation

Measurement	Expected value	Unit 1			Unit 2		
		NO via sample port	NO via calibration port	Dsc	NO via sample port	NO via calibration port	Dsc
	[ppb]	[ppb]	[ppb]	[%]	[ppb]	[ppb]	[%]
1	749,6	749,6	748,8		748,8	749,6	
2	749,6	749,6	749,6		749,6	750,4	
3	749,6	750,4	750,4		749,6	750,4	
4	749,6	749,6	748,8		749,6	749,6	
5	749,6	750,4	750,4		750,4	749,6	
6	749,6	750,4	750,4		750,4	750,4	
Average		750,0	749,7	0,0	749,7	750,0	0,0

7.5 Assessment

The analyser fulfils the requirements for the difference between sample and calibration port. For the calculation of the uncertainty $D_{SC} = 0$ is used.

Minimum requirement fulfilled? yes

7.6 Documentation

Refer to point 7.4.

7.3 Appendix G (normative) Type approval according to EN 14211

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

- 1) The value of each individual performance characteristic tested in the laboratory shall fulfill the criterion stated in table 1 (see 8.2 in EN 14211).
- 2) The expanded uncertainty calculated from the standard uncertainties due to the values of the specific performance characteristics obtained in the laboratory tests fulfils the criterion as stated in the Council Directive 99/30/EC. This criterion is the maximum uncertainty of hourly values of continuous measurements at the hourly limit value. The relevant specific performance characteristics and the calculation procedure are given in annex G of the EN 14211.
- 3) The value of each of the individual performance characteristics tested in the field shall fulfill the criterion stated in table 1 (see 8.2 of the EN 14211).
- 4) The expanded uncertainty calculated from the standard uncertainties due to the values of the specific performance characteristics obtained in the laboratory and field tests fulfils the criterion as stated in the Council Directive 99/30/EC. This criterion is the maximum uncertainty of hourly values of continuous measurements at the hourly limit value. The relevant specific performance characteristics and the calculation procedure are given in annex G of the EN 14211.

7.2 Equipment

Here not necessary.

7.3 Testing

At the end of the testing all elementary uncertainties have been calculated from of the test data.

7.4 Evaluation

- to 1) The value of each single tested performance characteristic in the lab fulfils the criterion of the EN 14211.
- to 2) The expanded uncertainty, calculated of the specific performance characteristics obtained in the laboratory tests, fulfils the performance criterion.
- to 3) The value of each single tested performance characteristic in the field fulfils the criterion of the EN 14211.
- to 4) The expanded uncertainty, calculated of the specific performance characteristics obtained in the laboratory and the field tests, fulfils the performance criterion.

7.5 Assessment

The minimum requirements are kept.

Minimum requirement fulfilled? yes

7.6 Documentation

The results to the topics 1 and 3 are summarized in Table 49.

The results of topic 2 can be found in Table 50 and in Table 51.

The results of topic 4 can be found in Table 52 and in Table 53.

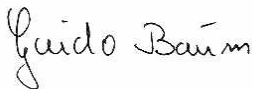
8 Recommendations for the use in practice

8.1 Work in the maintenance interval

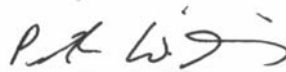
In addition to the usual calibrating work it is important to frequently check the state of the inlet contained Teflon filter in front of the analyser, that can cause a reduction of the sample flow in case of too strong seizure with dust. The duration of the replacement interval of the filters which are to prevent the pollution of the devices through the sucked ambient air depends on the dust load at the location of installation. The alternating interval is committed to one month.

By the way, the statements of the manufacturer are to be considered.

Department of Environmental protection



Dipl.-Ing. Guido Baum



Dr. Peter Wilbring

Cologne, January 5, 2006
936/21203248/C1

9 Literature

- VDI 4202 Part 1: Minimum requirements for suitability tests of automated ambient air quality measuring systems; Point-related measurement methods of gaseous and particulate pollutants, from June 2002
- VDI 4203 Part 3: Testing of automated measuring systems; Test procedures for point-related ambient air quality measuring systems of gaseous and particulate pollutants, from August 2004
- EN 14211 Ambient air quality - Standard method for the measurement of the concentration of nitrogen dioxide and nitrogen monoxide by chemiluminescence, from July 2005
- VDI 2453 Blatt 2: 2002-10 Messen gasförmiger Immissionen; Messen der Stickstoffmonoxid- und Stickstoffdioxidkonzentration; Kalibrierung von NO/NO_x Chemilumineszenz-Messgeräten mit Hilfe der Gasphasentitration. Berlin: Beuth Verlag
- VDI 2453 Blatt 1: 1990-10 Messen gasförmiger Immissionen; Messen der Stickstoffdioxidkonzentration; Manuelles photometrisches Basisverfahren (Saltzman). Berlin: Beuth Verlag
- Richtlinie 96/62/EG des Rates vom 27. September 1996 über die Beurteilung und die Kontrolle der Luftqualität ABl. L 296, S. 55
- Richtlinie 1999/30/EG des Rates vom 22. April 1999 über Grenzwerte für Schwefeldioxid, Stickstoffdioxid und Stickstoffoxide, Partikel und Blei in der Luft, ABl. L 163, S. 41
- Richtlinie 2000/69/EG des Europäischen Parlaments vom 16. November 2000 über Grenzwerte für Benzol und Kohlenmonoxid in der Luft, ABl. Nr. L 313, S. 12
- Gemeinsamer Standpunkt (EG) Nr. 16/2001 vom Rat festgelegt am 8. März 2001 im Hinblick auf den Erlass der Richtlinie 2001/.../EG des Europäischen Parlaments und des Rates vom ... über den Ozongehalt der Luft, ABl. C 126. S. 1/24

10 Appendix

Appendix 1: Requirements according to EN 14211

Appendix 2: Measured and calculated values

Appendix 3: Manual

Appendix 1 : Requirements according to EN 14211

Table 49: Summary of the performance standards according to EN 14211

Performance characteristic	Criterion	Test result	ful-filled?	Page
8.4.5 Repeatability standard deviation at zero	$\leq 1,0 \text{ nmol/mol}$	Device 1: 0.17 nmol/mol Device 2: 0.21 nmol/mol	yes	43
8.4.5 Repeatability standard deviation at concentration c_t	$\leq 3,0 \text{ nmol/mol}$	Device 1: 1.13 nmol/mol Device 2: 1.21 nmol/mol	yes	43
8.4.6 Lack of fit (residual from the linear regression function)	Highest deviation from the linear regression function for concentrations higher than zero $\leq 4 \%$ of the measured value Deviation at zero $\leq 5,0 \text{ nmol/mol}$	At zero point: Device 1: 0.24 nmol/mol Device 2: 0.48 nmol/mol At span point: Device 1: 7.52 nmol/mol corresponds to 0.8 % of nominal Device 2: 2.08 nmol/mol corresponds to 1.3 % of nominal	yes	36
8.4.7 Sensitivity coefficient of the sample gas pressure	$\leq 8,0 \text{ nmol/mol/kPa}$	Device 1: 0.07 nmol/mol/kPa Device 2: 0.08 nmol/mol/kPa	yes	94
8.4.8 Sensitivity coefficient of the sample gas temperature	$\leq 3,0 \text{ nmol/mol/K}$	Device 1: -0.31 nmol/mol/K Device 2: -0.30 nmol/mol/K	yes	96
8.4.9 Sensitivity coefficient of surrounding temperature	$\leq 3,0 \text{ nmol/mol/K}$	At zero point: Device 1: 0.05 nmol/mol/K Device 2: 0.18 nmol/mol/K At span point: Device 1: 0.39 nmol/mol/K Device 2: 0.37 nmol/mol/K	yes	51 55
8.4.10 Sensitivity coefficient of electrical voltage	$\leq 0,3 \text{ nmol/mol/V}$	Device 1: 0.04 nmol/mol/V Device 2: 0.04 nmol/mol/V	yes	76
8.4.11 Interferents at zero and at concentration c_t (at a level of the 8-hour mean limit value)	H ₂ O $\leq 5,0 \text{ nmol/mol}$ CO ₂ $\leq 5,0 \text{ nmol/mol}$ O ₃ $\leq 2,0 \text{ nmol/mol}$ NH ₃ $\leq 5,0 \text{ nmol/mol}$	Device 1: H ₂ O 0.83 nmol/mol at zero point -1.34 nmol/mol at span point CO ₂ -0.10 nmol/mol at zero point -2.33 nmol/mol at span point O ₃ -0.07 nmol/mol at zero point -0.34 nmol/mol at span point NH ₃ -0.04 nmol/mol at zero point	yes	67

		-1.00 nmol/mol at span point Device 2: H ₂ O 0.87 nmol/mol at zero point -1.00 nmol/mol at span point CO ₂ -0.10 nmol/mol at zero point -1.66 nmol/mol at span point O ₃ -0.20 nmol/mol at zero point -0.34 nmol/mol at span point NH ₃ 0.07 nmol/mol at zero point -1.00 nmol/mol at span point		
8.4.12 Averaging effect	≤ 7,0 % of the measured value	Device 1: -2.68 % Device 2: -1.10 %	yes	75
8.4.13 Difference sample/calibration port	≤ 1,0 %	Device 1: 0,0 % Device 2: 0,0 %	yes	102
8.4.3 Response time (rise)	≤ 180 s	Device 1: 78 s Device 2: 79 s	yes	48
8.4.3 Response time (fall)	≤ 180 s	Device 1: 83 s Device 2: 81 s	yes	48
8.4.3 Difference between rise time and fall time	≤ 10 % relative difference or 10 s, depending on which value is higher	Device 1: 3.2 %. absolute 5s Device 2: 3.3 %. absolute 3s	yes	48
8.4.14 Efficiency of the converter	≥ 98%	Device 1: 98 % Device 2: 98 %	yes	86
8.5.6 Period of unattended operation	3 month or less if the manufacturer specifies a shorter period, but not less than 2 weeks	3 months	yes	88
8.5.7 Availability of the analyser	> 90 %	96 %	yes	84
8.5.5 Reproducibility standard deviation under field conditions	≤ 5,0 % of the average over a period of 3 month	3.85 %	yes	70
8.5.4 Long-term drift at zero	≤ 5,0 nmol/mol	Device 1: 0.036 nmol/mol / 3 months Device 2: 0.036 nmol/mol / 3 months	yes	59
8.5.4 Long-term drift at span level	≤ 5,0 % of the maximum of the tested range	Device 1: 2.61 nmol/mol / 3 months = 0.27 % Device 2: 0.63 nmol/mol / 3 months = 0.06 %	yes	63
8.4.4 Short-term drift at zero	≤ 2,0 nmol/mol over 12 h	Device 1: 0.32 nmol/mol Device 2: 0.40 nmol/mol	yes	98
8.4.4 Short-term drift at span level	≤ 6,0 nmol/mol over 12 h	Device 1: 0.16 nmol/mol Device 2: 0.48 nmol/mol	yes	99



Table 50: Expanded uncertainty out of the results from the lab test EN 14211, device 1

Instrument: Thermo Model 42i		serial no. Device 1				
component NO/NO2		1h-limit value: 505		nmol/mol		
No.	Performance characteristic	Performance criteria	result	partial uncertainty	Square of uncertainty	
1	Repeatability at zero	1,0 nmol/mol	0,170	$u_{r,z}$	0,03	0,0006
2	Repeatability at concentration ct	3,0 nmol/mol	1,130	$u_{r,jv}$	0,15	0,0215
3	"lack of fit"	4,0%	0,800	u_{lf}	2,33	5,4405
4	Sensitivity coefficient of sample gas pressure	8,0 nmol/mol/kPa	0,070	u_{gp}	3,06	9,3722
5	Sensitivity coefficient of sample gas temperature	3,0 nmol/mol/K	-0,310	u_{gt}	-4,30	18,5245
6	Sensitivity coefficient of surrounding temperature	3,0 nmol/mol/K	0,390	u_{st}	5,41	29,3192
7	Sensitivity coefficient of electrical voltage	0,30 nmol/mol/V	0,040	u_v	0,78	0,6162
8a	H2O with concentration 21 mmol/mol	5,0 nmol/mol	-1,371	u_{H2O}	0,93	0,8562
8b	CO2 with concentration 500 µmol/mol	5,0 nmol/mol	-2,205	$u_{int,pos}$	2,01	4,0275
8c	O3 with concentration 200 nmol/mol	2,0 nmol/mol	-0,325	or		
8d	NH3 with concentration 200 nmol/mol	5,0 nmol/mol	-0,946	$u_{int,neg}$		
9	Averaging effect	7,0%	-2,680	u_{av}	-7,81	61,0564
18	Difference sample/calibration port	1,0%	0,000	u_{disc}	0,00	0,0000
21	Converter efficiency	98,0%	98,000	u_{EC}	5,83	34,0033
22	Increase of NO2 concentration due to residence time	4,0 nmol/mol	2,200	u_{ctr}	6,41	41,1440
23	Uncertainty calibration gas	3,0%	2,000	u_{cg}	5,05	25,5025
				combined standard uncertainty	u_c	15,1627 nmol/mol
				expanded uncertainty	U_c	30,3254 nmol/mol
				expanded uncertainty actual	$U_{c,rel}$	6,01 %
				expanded uncertainty required	$U_{req,rel}$	15 %

Table 51: Expanded uncertainty out of the results from the lab test EN 14211, device 2

Instrument: Thermo Model 42i		serial no. Device 2				
component NO/NO2		1h-limit value: 505		nmol/mol		
No.	Performance characteristic	Performance criteria	result	partial uncertainty	Square of uncertainty	
1	Repeatability at zero	1,0 nmol/mol	0,210	$u_{r,z}$	0,03	0,0010
2	Repeatability at concentration ct	3,0 nmol/mol	1,210	$u_{r,jv}$	0,16	0,0242
3	"lack of fit"	4,0%	1,300	u_{lf}	3,79	14,3664
4	Sensitivity coefficient of sample gas pressure	8,0 nmol/mol/kPa	0,080	u_{gp}	3,50	12,2412
5	Sensitivity coefficient of sample gas temperature	3,0 nmol/mol/K	-0,300	u_{gt}	-4,17	17,3486
6	Sensitivity coefficient of surrounding temperature	3,0 nmol/mol/K	0,370	u_{st}	5,14	26,3892
7	Sensitivity coefficient of electrical voltage	0,30 nmol/mol/V	0,040	u_v	0,78	0,6162
8a	H2O with concentration 21 mmol/mol	5,0 nmol/mol	-1,007	u_{H2O}	0,68	0,4622
8b	CO2 with concentration 500 µmol/mol	5,0 nmol/mol	-1,582	$u_{int,pos}$	1,65	2,7153
8c	O3 with concentration 200 nmol/mol	2,0 nmol/mol	-0,332	or		
8d	NH3 with concentration 200 nmol/mol	5,0 nmol/mol	-0,940	$u_{int,neg}$		
9	Averaging effect	7,0%	-1,100	u_{av}	-3,21	10,2860
18	Difference sample/calibration port	1,0%	0,000	u_{disc}	0,00	0,0000
21	Converter efficiency	98,0%	98,000	u_{EC}	5,83	34,0033
22	Increase of NO2 concentration due to residence time	4,0 nmol/mol	2,200	u_{ctr}	6,41	41,1440
23	Uncertainty calibration gas	3,0%	2,000	0	5,05	25,5025
				combined standard uncertainty	u_c	13,6061 nmol/mol
				expanded uncertainty	U_c	27,2122 nmol/mol
				expanded uncertainty actual	$U_{c,rel}$	5,39 %
				expanded uncertainty required	$U_{req,rel}$	15 %

Table 52: Expanded uncertainty out of the results from the lab and field test EN 14211, device 1

Instrument: Thermo Model 42i		serial no. Device 1			
component NO/NO ₂		1h-limit value: 505		nmol/mol	
No.	Performance characteristic	Performance criteria	result	partial uncertainty	Square of uncertainty
1	Repeatability at zero	1,0 nmol/mol	0.170	$u_{r,z}$	0.03
2	Repeatability at concentration ct	3,0 nmol/mol	1.130	$u_{r,v}$	not considered, as $u_{r,v} = 0,14 < u_{r,f}$
3	"lack of fit"	4.0%	0.800	$u_{l,v}$	2.33
4	Sensitivity coefficient of sample gas pressure	8,0 nmol/mol/kPa	0.070	u_{sp}	3.06
5	Sensitivity coefficient of sample gas temperature	3,0 nmol/mol/K	-0.310	u_{gt}	-4.30
6	Sensitivity coefficient of surrounding temperature	3,0 nmol/mol/K	0.390	u_{st}	5.41
7	Sensitivity coefficient of electrical voltage	0,30 nmol/mol/V	0.040	u_v	0.78
8a	H ₂ O with concentration 21 mmol/mol	5,0 nmol/mol	-1.371	u_{H_2O}	0.93
8b	CO ₂ with concentration 500 µmol/mol	5,0 nmol/mol	-2.205	$u_{nt,pos}$	2.01
8c	O ₃ with concentration 200 nmol/mol	2,0 nmol/mol	-0.325	or	
8d	NH ₃ with concentration 200 nmol/mol	5,0 nmol/mol	-0.946	$u_{nt,neg}$	
9	Averaging effect	7.0%	-2.680	u_{av}	-7.81
10	Reproducibility under field conditions	5.0% of the average of 3 Mon.	3.850	$u_{r,f}$	4.03
11	Long term drift at zero level	5,0 nmol/mol	0.036	$u_{d,z}$	0.02
12	Long term drift at span level	5.0% of max. of certification range	0.270	$u_{d,v}$	0.79
18	Difference sample/calibration port	1.0%	0.000	u_{Dsc}	0.00
21	Converter efficiency	98.0%	98.000	u_{EC}	5.83
22	Increase of NO ₂ concentration due to residence time	4,0 nmol/mol	2.200	u_{ct}	6.41
23	Uncertainty calibration gas	3.0%	2.000	u_{cg}	5.05
combined standard uncertainty				u_c	16.2148
expanded uncertainty				U_c	32.4296
expanded uncertainty actual				$U_{c,rel}$	6.42
expanded uncertainty required				$U_{req,rel}$	15

Table 53: Expanded uncertainty out of the results from the lab and field test EN 14211, device 2

Instrument: Thermo Model 42i		serial no. Device 2			
component NO/NO ₂		1h-limit value: 505		nmol/mol	
No.	Performance characteristic	Performance criteria	result	partial uncertainty	Square of uncertainty
1	Repeatability at zero	1,0 nmol/mol	0.210	$u_{r,z}$	0.03
2	Repeatability at concentration ct	3,0 nmol/mol	1.210	$u_{r,v}$	not considered, as $u_{r,v} = 0,15 < u_{r,f}$
3	"lack of fit"	4.0%	1.300	$u_{l,v}$	3.79
4	Sensitivity coefficient of sample gas pressure	8,0 nmol/mol/kPa	0.080	u_{sp}	3.50
5	Sensitivity coefficient of sample gas temperature	3,0 nmol/mol/K	-0.300	u_{gt}	-4.17
6	Sensitivity coefficient of surrounding temperature	3,0 nmol/mol/K	0.370	u_{st}	5.14
7	Sensitivity coefficient of electrical voltage	0,30 nmol/mol/V	0.040	u_v	0.78
8a	H ₂ O with concentration 21 mmol/mol	5,0 nmol/mol	-1.007	u_{H_2O}	0.68
8b	CO ₂ with concentration 500 µmol/mol	5,0 nmol/mol	-1.582	$u_{nt,pos}$	1.65
8c	O ₃ with concentration 200 nmol/mol	2,0 nmol/mol	-0.332	or	
8d	NH ₃ with concentration 200 nmol/mol	5,0 nmol/mol	-0.940	$u_{nt,neg}$	
9	Averaging effect	7.0%	-1.100	u_{av}	-3.21
10	Reproducibility under field conditions	5.0% of the average of 3 Mon.	3.850	$u_{r,f}$	4.03
11	Long term drift at zero level	5,0 nmol/mol	0.036	$u_{d,z}$	0.02
12	Long term drift at span level	5.0% of max. of certification range	0.060	$u_{d,v}$	0.17
18	Difference sample/calibration port	1.0%	0.000	u_{Dsc}	0.00
21	Converter efficiency	98.0%	98.000	u_{EC}	5.83
22	Increase of NO ₂ concentration due to residence time	4,0 nmol/mol	2.200	u_{ct}	6.41
23	Uncertainty calibration gas	3.0%	2.000	0	5.05
combined standard uncertainty				u_c	14.7493
expanded uncertainty				U_c	29.4987
expanded uncertainty actual				$U_{c,rel}$	5.84
expanded uncertainty required				$U_{req,rel}$	15

Appendix 2 : Measured and calculated values

Table 54: Linearity NO₂ Thermo 42i 1/5

Manufacturer	Thermo	Zero gas	Synth. air	Span gas	Permeation system
Type	42i	Manufacturer	Praxair	Manufacturer	MCZ
Measuring range	0 to 400 µg/m ³			Test	1 of 5
Component	NO ₂				
No.	Values Expectancy [µg/m ³]	Measured [µg/m ³]	Regression		
Unit 1	0	0.6			
	45	44.4			
	90	88.2			
	125	122			
	150	150.8			
	185	185			
	225	221			
	265	264			
	310	307	Slope		0.9931
	350	348	Intercept		-0.2356
	400	396			
	500	497	Correlation coefficient		0.999
Unit 2	0	0.9			
	45	45.7			
	90	91.8			
	125	125			
	150	153.9			
	185	188			
	225	226			
	265	269			
	310	312	Slope		1.0008
	350	353	Intercept		1.6035
	400	399			
	500	502	Correlation coefficient		0.999

Table 55: Linearity NO₂ Thermo 42i 2/5

Manufacturer	Thermo	Zero gas	Synth. air	Span gas	Permeation system
Type	42i	Manufacturer	Praxair	Manufacturer	MCZ 42i
Measuring range	0 to 400 µg/m³			Test	2 of 5
Component	NO₂				0 to 400 µg/m³
					NO₂
No.	Values	Expectancy	Measured	Regression	
		[µg/m³]	[µg/m³]		
Unit 1	0		0.8		
	45		44		
	90		87.8		
	125		123		
	150		152		
	185		187		
	225		224		
	265		266		
	310		308	Slope	0.9962
	350		348	Intercept	0.1425
	400		397		
	500		499	Correlation coefficient	0.999
Unit 2	0		1		
	45		46.2		
	90		92.1		
	125		126		
	150		150.2		
	185		188		
	225		225		
	265		266		
	310		313	Slope	1.0027
	350		352	Intercept	0.9481
	400		401		
	500		503	Correlation coefficient	1

Table 56: Linearity NO₂ Thermo 42i 3/5

Manufacturer	Thermo	Zero gas	Synth. air	Span gas	Permeation system
Type	42i	Manufacturer	Praxair	Manufacturer	MCZ 42i
Measuring range	0 to 400 µg/m³			Test	3 of 5 0 to 400 µg/m³
Component	NO₂				NO₂
No.	Values	Expectancy	Measured	Regression	
		[µg/m³]	[µg/m³]		
Unit 1	0		0.3		
	45		43		
	90		87.8		
	125		123		
	150		150		
	185		184		
	225		222		
	265		264		
	310		308	Slope	0.9962
	350		349	Intercept	-0.82
	400		397		
	500		497	Correlation coefficient	1
Unit 2	0		0.7		
	45		46.3		
	90		90.4		
	125		124		
	150		152		
	185		186		
	225		225		
	265		267		
	310		311	Slope	1.0006
	350		353	Intercept	0.7319
	400		399		
	500		501	Correlation coefficient	0.999

Table 57: Linearity NO₂ Thermo 42i 4/5

Manufacturer	Thermo	Zero gas	Synth. air	Span gas	Permeation system
Type	42i	Manufacturer	Praxair	Manufacturer	MCZ 42i
Measuring range	0 to 400 µg/m³			Test	4 of 5
Component	NO₂				0 to 400 µg/m³
					NO₂
No.	Values	Expectancy	Measured	Regression	
		[µg/m³]	[µg/m³]		
Unit 1	0		0.6		
	45		45.2		
	90		88.9		
	125		125.2		
	150		151		
	185		186		
	225		226		
	265		265		
	310		308	Slope	0.9938
	350		349	Intercept	0.9483
	400		397		
	500		498	Correlation coefficient	0.999
Unit 2	0		0.6		
	45		46.1		
	90		91.2		
	125		126		
	150		151.7		
	185		186		
	225		225		
	265		266		
	310		312	Slope	0.9993
	350		352	Intercept	1.2003
	400		402		
	500		499	Correlation coefficient	1

Table 58: Linearity NO₂ Thermo 42i 5/5

Manufacturer	Thermo	Zero gas	Synth. air	Span gas	Permeation system
Type	42i	Manufacturer	Praxair	Manufacturer	MCZ 42i
Measuring range	0 to 400 µg/m³			Test	5 of 5
Component	NO₂				0 to 400 µg/m³
					NO₂
No.	Values	Expectancy	Measured	Regression	
		[µg/m³]	[µg/m³]		
Unit 1	0		0.8		
	45		45		
	90		89.6		
	125		124.1		
	150		149.8		
	185		185.4		
	225		225.2		
	265		265		
	310		309	Slope	0.9986
	350		351	Intercept	0.1408
	400		398		
	500		500	Correlation coefficient	1
Unit 2	0		0.8		
	45		45.2		
	90		90.4		
	125		125		
	150		151		
	185		187		
	225		226		
	265		266		
	310		310	Slope	1.0048
	350		352	Intercept	0.0528
	400		401		
	500		504	Correlation coefficient	1

Table 59: Linearity NO Thermo 42i 1/5

Manufacturer	Thermo	Zero gas	Synth. air	Span gas	NO cylinder
Type	42i	Manufacturer	Praxair	Manufacturer	Air Liquide
Measuring range	0 to 1200 µg/m³			Test	1 of 5
Component	NO				
No.	Values Expectancy [µg/m³]	Measured [µg/m³]	Regression		
Unit 1	0	0.4	Slope Intercept Correlation coefficient		
	200	198			
	400	399			
	600	604			
	800	805			
	1000	1003			
	1200	1211			
			1.009		
Unit 2	0	0.8	Slope Intercept Correlation coefficient		
	200	201			
	400	404			
	600	607			
	800	809			
	1000	1010			
	1200	1224			
			1.0165		

Table 60: Linearity NO Thermo 42i 2/5

Manufacturer	Thermo	Zero gas	Synth. air	Span gas	NO cylinder
Type	42i	Manufacturer	Praxair	Manufacturer	Air Liquide
Measuring range	0 to 1200 µg/m³			Test	2 of 5
Component	NO				
No.		Values Expectancy [µg/m³]	Measured [µg/m³]	Regression	
Unit 1		0	0.3		
		200	199		
		400	402		
		600	606		
		800	801		
		1000	1007		
		1200	1214		
				Slope	1.01
				Intercept	-1.825
				Correlation coefficient	1
Unit 2		0	0.6		
		200	203		
		400	401		
		600	598		
		800	798		
		1000	1005		
		1200	1209		
				Slope	1.0047
				Intercept	-0.7214
				Correlation coefficient	0.999

Table 61: Linearity NO Thermo 42i 3/5

Manufacturer	Thermo	Zero gas	Synth. air	Span gas	NO cylinder
Type	42i	Manufacturer	Praxair	Manufacturer	Air Liquide
Measuring range	0 to 1200 µg/m³			Test	3 of 5
Component	NO				
No.		Values		Regression	
		Expectancy	Measured		
		[µg/m³]	[µg/m³]		
Unit 1		0	0.1		
		200	201		
		400	404		
		600	603		
		800	805		
		1000	1011		
		1200	1221		
				Slope	1.0149
				Intercept	-2.525
				Correlation coefficient	0.999
Unit 2		0	0.4		
		200	204		
		400	397		
		600	608		
		800	806		
		1000	994		
		1200	1190		
				Slope	0.9925
				Intercept	4.4357
				Correlation coefficient	0.999

Table 62: Linearity NO Thermo 42i 4/5

Manufacturer	Thermo	Zero gas	Synth. air	Span gas	NO cylinder
Type	42i	Manufacturer	Praxair	Manufacturer	Air Liquide
Measuring range	0 to 1200 µg/m³			Test	4 of 5
Component	NO				
No.		Values Expectancy [µg/m³]	Measured [µg/m³]	Regression	
Unit 1		0	0.1		
		200	202		
		400	403		
		600	605		
		800	801		
		1000	1003		
		1200	1193		
				Slope	0.9962
				Intercept	3.2964
				Correlation coefficient	0.999
Unit 2		0	0.5		
		200	203		
		400	402		
		600	599		
		800	806		
		1000	1022		
		1200	1231		
				Slope	1.0238
				Intercept	-5.2321
				Correlation coefficient	0.999

Table 63: Linearity NO Thermo 42i 5/5

Manufacturer	Thermo	Zero gas	Synth. air	Span gas	NO cylinder
Type	42i	Manufacturer	Praxair	Manufacturer	Air Liquide
Measuring range	0 to 1200 µg/m³			Test	5 of 5
Component	NO				
No.	Values	Expectancy	Measured	Regression	
		[µg/m³]	[µg/m³]		
Unit 1	0		0.4		
	200		201		
	400		406		
	600		600		
	800		798		
	1000		1007		
	1200		1208		
				Slope	1.0048
				Intercept	0.0429
				Correlation coefficient	0.999
Unit 2	0		0.7		
	200		202		
	400		405		
	600		604		
	800		810		
	1000		1004		
	1200		1208		
				Slope	1.0055
				Intercept	1.5036
				Correlation coefficient	1

Table 64: Cross-sensitivities at the zero level unit 1 (NO₂ channel)

Interferents		1. Rev.	2. Rev.	3. Rev.	Average	Deviation
	mg/m ³	ZP	ZP	ZP	ZP	ZP
CO ₂	SL	-0.6	-0.5	-0.7	-0.60	
	700	-0.7	-0.6	0	-0.43	0.17
CO	SL	-0.8	-0.6	-0.8	-0.73	
	60	-0.9	-0.8	-0.9	-0.87	-0.14
H ₂ O	SL	0	0	-0.4	-0.13	
	ca. 50 % rel.	1.2	1	0.9	1.03	1.16
SO ₂	SL	-0.7	-0.9	-0.8	-0.80	
	0.7	-0.6	-0.6	-0.8	-0.67	0.13
NO	SL	-0.7	-0.8	-0.7	-0.73	
	1	-0.8	-0.7	-0.9	-0.80	-0.07
Ozone	SL	-0.5	-0.1	0.2	-0.13	
	0.36	-0.1	0.1	-0.1	-0.03	0.10
N ₂ O	SL	0.1	0.5	0.3	0.30	
	0.5	0.9	0.7	-0.2	0.47	0.17
H ₂ S	SL	-0.7	-0.6	-0.6	-0.63	
	0.03	-0.6	-0.4	-0.3	-0.43	0.20
NH ₃	SL	-1	-1	-0.8	-0.93	
	0.03	-0.9	-0.8	-0.8	-0.83	0.10
Benzene	SL	0.9	1	1.1	1.00	
	1	1.2	1.4	0.8	1.13	0.13
		Sum of negative deviations				-0.21
		Sum of positive deviations				2.16

Table 65: Cross-sensitivities at the zero level unit 2 (NO₂ channel)

Interferents		1. Rev.	2. Rev.	3. Rev.	Average	Deviation
	mg/m ³	ZP	ZP	ZP	ZP	ZP
CO ₂	SL	-0.2	-0.2	-0.3	-0.23	
	700	0.1	-0.2	-0.1	-0.07	0.16
CO	SL	-0.8	-0.6	-0.8	-0.73	
	60	-0.9	-0.8	-0.9	-0.87	-0.14
H ₂ O	SL	-0.1	0	0.1	0.00	
	ca. 50 % rel.	1.1	1	0.8	0.97	0.97
SO ₂	SL	-0.5	-0.8	-0.6	-0.63	
	0.7	-0.6	-0.8	-0.7	-0.70	-0.07
NO	SL	-0.4	-0.7	-0.5	-0.53	
	1	-0.7	-0.7	-0.4	-0.60	-0.07
Ozone	SL	0.9	0.9	0.4	0.73	
	0.36	1.4	0.4	0.1	0.63	-0.10
N ₂ O	SL	-0.4	-0.2	-0.2	-0.27	
	0.5	0.1	0.1	0.3	0.17	0.44
H ₂ S	SL	-0.4	-0.2	-0.3	-0.30	
	0.03	-0.3	-0.1	-0.1	-0.17	0.13
NH ₃	SL	-0.3	-0.4	-0.3	-0.33	
	0.03	-0.2	-0.2	-0.2	-0.20	0.13
Benzene	SL	1.1	1.8	1.4	1.43	
	1	1.6	1.7	1.4	1.57	0.14
		Sum of negative deviations				-0.38
		Sum of positive deviations				1.97

Table 66: Cross-sensitivities at the span level unit 1 (NO₂ channel)

Interferents		1. Rev.	2. Rev.	3. Rev.	Average	Deviation
	mg/m ³	SP	SP	SP	SP	SP
CO ₂	SL	405	403	402	403.33	
	700	403	401	399	401.00	-2.33
CO	SL	398	400	400	399.33	
	60	400	402	401	401.00	1.67
H ₂ O	SL	395	393	394	394.00	
	ca. 50 % rel.	390	388	390	389.33	-4.67
SO ₂	SL	376	376	376	376.00	
	0.7	376	374	375	375.00	-1.00
NO	SL	400	400	400	400.00	
	1	399	401	399	399.67	-0.33
Ozone	SL	383	384	384	383.67	
	0.36	383	383	384	383.33	-0.33
N ₂ O	SL	375	374	373	374.00	
	0.5	374	374	375	374.33	0.33
H ₂ S	SL	373	373	373	373.00	
	0.03	372	372	373	372.33	-0.67
NH ₃	SL	381	384	384	383.00	
	0.03	382	382	381	381.67	-1.33
Benzene	SL	378	378	377	377.67	
	1	376	376	377	376.33	-1.33
		Sum of negative deviations				-11.99
		Sum of positive deviations				2.00

Table 67: Cross-sensitivities at the span level unit 2 (NO₂ channel)

Interferents		1. Rev.	2. Rev.	3. Rev.	Average	Deviation
	mg/m ³	SP	SP	SP	SP	SP
CO ₂	SL	403	402	400	401.67	
	700	402	403	398	401.00	-0.67
CO	SL	398	399	399	398.67	
	60	400	400	398	399.33	0.67
H ₂ O	SL	393	392	391	392.00	
	ca. 50 % rel.	388	386	387	387.00	-5.00
SO ₂	SL	375	373	374	374.00	
	0.7	376	373	373	374.00	0.00
NO	SL	399	401	402	400.67	
	1	400	401	403	401.33	0.67
Ozone	SL	375	375	374	374.67	
	0.36	375	375	375	375.00	0.33
N ₂ O	SL	382	382	382	382.00	
	0.5	382	383	385	383.33	1.33
H ₂ S	SL	369	368	375	370.67	
	0.03	368	368	376	370.67	0.00
NH ₃	SL	382	382	383	382.33	
	0.03	382	381	381	381.33	-1.00
Benzene	SL	377	376	376	376.33	
	1	377	376	375	376.00	-0.33
		Sum of negative deviations				-7.00
		Sum of positive deviations				2.98

Table 68: Cross-sensitivities unit 1 (NO channel)

Unit 1 Zero level [ppb]						
Interferents		1. Rev.	2. Rev.	3. Rev.	Average	Deviation
	[ppb]	NP	NP	NP	NP	NP
CO ₂	SL	0.1	0.2	0.1	0.13	
	500 µmol/mol	0.1	0	0	0.03	-0.10
H ₂ O	SL	0	0.1	0.4	0.17	
	19 mmol/mol	0.5	0.5	2	1.00	0.83
Ozone	SL	0.1	0	-0.2	-0.03	
	200 nmol/mol	-0.1	-0.1	-0.1	-0.10	-0.07
NH ₃	SL	0	0	-0.1	-0.03	
	200 nmol/mol	0	-0.1	-0.1	-0.07	-0.04
Unit 1 Span level [ppb]						
Interferents		1. Rev.	2. Rev.	3. Rev.	Average	Deviation
	[ppb]	RP	RP	RP	RP	RP
CO ₂	SL	635	634	634	634.33	
	500 µmol/mol	634	633	632	632.00	-2.33
H ₂ O	SL	636	635	636	635.67	
	19 mmol/mol	634	634	635	634.33	-1.34
Ozone	SL	634	633	634	633.67	
	200 nmol/mol	632	634	634	633.33	-0.34
NH ₃	SL	635	636	635	635.33	
	200 nmol/mol	634	635	634	634.33	-1.00

Table 69: Cross-sensitivities unit 2 (NO channel)

Unit 2		Zero level [ppb]				
Interferents		1. Rev.	2. Rev.	3. Rev.	Average	Deviation
	[ppb]	NP	NP	NP	NP	NP
CO ₂	SL	0.1	0.1	0.1	0.10	
	500 µmol/mol	0	0	0	0.00	-0.10
H ₂ O	SL	0	0	0.3	0.10	
	19 mmol/mol	0.5	0.4	2	0.97	0.87
Ozone	SL	0.1	0.1	0	0.07	
	200 nmol/mol	0	-0.1	-0.3	-0.13	-0.20
NH ₃	SL	0	0.1	-0.1	0.00	
	200 nmol/mol	0	0.1	0.1	0.07	0.07
Unit 2		Span level [ppb]				
Interferents		1. Rev.	2. Rev.	3. Rev.	Average	Deviation
	[ppb]	RP	RP	RP	RP	RP
CO ₂	SL	641	642	641	641.33	
	500 µmol/mol	640	639	640	639.67	-1.66
H ₂ O	SL	638	637	639	638.00	
	19 mmol/mol	636	637	638	637.00	-1.00
Ozone	SL	639	641	639	639.67	
	200 nmol/mol	638	640	640	639.33	-0.34
NH ₃	SL	640	640	639	639.67	
	200 nmol/mol	638	639	639	638.67	-1.00

Table 70: Single values of the averaging-test according to EN 14211 Unit 1

Constant concentration		Variable concentration	
Independent Measurement	Measured value [ppb]	Independent Measurement	Measured value [ppb]
1	586.2	00:45	495
2	586.8	01:30	119
3	585.5	02:15	480
4	585.4	03:00	116
		03:45	489
		04:30	102
		05:15	479
		06:00	116
		06:45	492
		07:30	111
		08:15	479
		09:00	99
		09:45	488
		10:30	129
		11:15	494
		12:00	119
		12:45	481
		13:30	120
		14:15	496
		15:00	113
Average	586.0	Average	300.85
Uncertainty:	-2.68 %		

Table 71: *Single values of the averaging-test according to EN 14211 Unit 2*

Constant concentration		Variable concentration	
Independent Measurement	Measured value [ppb]	Time [min]	Measured value [ppb]
1	584.3	00:45	488
2	583.5	01:30	124
3	583.8	02:15	479
4	584.1	03:00	109
		03:45	472
		04:30	98
		05:15	478
		06:00	114
		06:45	481
		07:30	102
		08:15	489
		09:00	109
		09:45	476
		10:30	99
		11:15	472
		12:00	112
		12:45	479
		13:30	123
		14:15	478
		15:00	121
Average	583.9	Average	295.15
Uncertainty:	-1.10 %		

Table 72: Variation of the mains voltage at the zero level

Unit 1			Deviation		Deviation
Measurement	230 V	210 V	210 V zu 230 V	245 V	245 V zu 230 V
	[µg/m ³]	[µg/m ³]	[µg/m ³]	[µg/m ³]	[µg/m ³]
1	0.38	0.57	0.19	0.76	0.38
2	0.57	0.76	0.19	0.57	0.00
3	0.38	0.38	0.00	0.57	0.19

Unit 2			Deviation		Deviation
Measurement	230 V	210 V	210 V zu 230 V	245 V	245 V zu 230 V
	[µg/m ³]	[µg/m ³]	[µg/m ³]	[µg/m ³]	[µg/m ³]
1	0.19	0.57	0.38	0.96	0.77
2	0.76	0.57	-0.19	0.57	-0.19
3	0.38	0.76	0.38	0.76	0.38

Table 73: Variation of the mains voltage at the span level

Unit 1			Deviation		Deviation
Measurement	230 V	210 V	210 V zu 230 V	245 V	245 V zu 230 V
	[µg/m ³]	[µg/m ³]	[µg/m ³]	[µg/m ³]	[µg/m ³]
1	368.63	369.20	0.57	370.73	2.10
2	371.11	370.54	-0.57	371.50	0.39
3	370.35	371.11	0.76	371.11	0.76

Unit 2			Deviation		Deviation
Measurement	230 V	210 V	210 V zu 230 V	245 V	245 V zu 230 V
	[µg/m ³]	[µg/m ³]	[µg/m ³]	[µg/m ³]	[µg/m ³]
1	366.53	368.82	2.29	368.63	2.10
2	367.29	368.44	1.15	368.63	1.34
3	367.48	368.06	0.58	369.01	1.53

Table 74: Results of the mains frequency test

Zero point	Values in ppb												
Frequency	48 Hz			50 Hz			52 Hz			Average			Deviation
Measurement	1	2	3	1	2	3	1	2	3	48 Hz	50 Hz	52 Hz	48 Hz - 50 Hz
Channel													
NO	-0.5	-0.3	-0.6	-0.2	-0.1	-0.2	-0.6	-0.5	-0.6	-0.40	-0.17	-0.57	-0.17
NO ₂	0.3	0.3	0.2	0.4	0.3	0.5	0.3	0.3	0.4	0.33	0.40	0.33	0.00
NO _x	-0.2	0	-0.4	0.2	0.2	0.3	-0.3	-0.2	-0.2	-0.07	0.23	-0.23	-0.17

Span point NO ₂	Values in ppb												
Frequency	48 Hz			50 Hz			52 Hz			Average			Deviation
Measurement	1	2	3	1	2	3	1	2	3	48 Hz	50 Hz	52 Hz	48 Hz - 50 Hz
Channel													
NO	0	-0.2	-0.1	0	-0.1	-0.2	-0.1	-0.1	-0.1	-0.10	-0.10	-0.10	0.00
NO ₂	152.1	148.8	148.7	153.2	151	150.8	155.3	154.1	153.8	149.87	151.67	154.40	4.53
NO _x	152.1	148.6	148.6	153.2	150.9	150.6	155.2	154	153.7	149.77	151.57	154.30	4.53

Span point NO	Values in ppb												
Frequency	48 Hz			50 Hz			52 Hz			Average			Deviation
Measurement	1	2	3	1	2	3	1	2	3	48 Hz	50 Hz	52 Hz	48 Hz - 50 Hz
Channel													
NO	198	199	200	201	203	203	206	208	207	199.00	202.33	207.00	8.00
NO ₂	9	8	8	8	8	7	8	7	7	8.33	7.67	7.33	-1.00
NO _x	207	207	208	210	211	210	214	214	215	207.33	210.33	214.33	7.00



Figure 21: Reading of the software version at the analyser display

Appendix 3 : Manual