TÜV IMMISSIONSSCHUTZ
UND ENERGIESYSTEME GMBH

Translation of the report on the suitability test of the ambient air measuring system CO Analyser Model 48i of the company Thermo Electron Corporation for the component Carbon monoxide

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Translation of the report on the suitability test of the ambient air measuring system CO Analyser Model 48i of the company Thermo Electron Corporation for the component Carbon monoxide

Measuring system tested:	CO Analyser Model 48i
Manufacturer of the Instrument:	Thermo Electron Corporation 27 Forge Parkway Franklin, MA 02038 USA Frauenauracher Straße 96 91056 Erlangen Germany
Time period of testing:	June 2005 to December 2005
Date of report:	January 5, 2006
Number of report:	936/21203248/A1
Scope of report:	In total 459 pages appendix from page 94 manual from page 117 with 342 pages

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1 Summary and proposal for declaration of suitability

1.1 Abstract

The report 936/21203248/A1 at hand is a revised version of the suitability test report 936/21203248/A 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 14626.

By order of Thermo Electron Corporation the TÜV Immissionsschutz und Energiesysteme GmbH has accomplished the suitability test of the measuring system CO Analyser Model 48i for the component Carbon monoxide.

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 14626 Ambient air quality - Standard method for the measurement of the concentration of carbon monoxide by non dispersive infrared spectroscopy, from July 2005

The measuring system tested operates using the NDIR-principle (non dispersive infrared spectroscopy).

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		
Carbon monoxide	CO	60	mg/m³	VDI 4202 part 1
Carbon monoxide	CO	100	mg/m³	EN 14626

Note: 0 – 100 ppm correlates to 0 – 100 µmol/mol CO or 0 – 116 mg/m³
(at 293 K and 1013 mbar)

The minimum requirements and the requirements of EN 14626 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 carbon monoxide 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 carbon monoxide concentration in the ambient air
1.2.2	**Name of device**	:	CO Analyser Model 48i
1.2.3	**Measured components**	:	Carbon monoxide
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 carbon monoxide in stationary operation
1.2.6	**Measuring ranges during the suitability test**	:	0 to 60 mg/m³ carbon monoxide 0 to 100 mg/m³ carbon monoxide
1.2.7	**Software version**	:	V 01.02.14.097
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/A1 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 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 subtests 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	28
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	35
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.	As given in Table 8 and Table 9, the two candidates meet the requirements of the guideline of VDI 4202	yes	37
5.2.5 Detection limit	Maximum B_0.	The detection limit is with 0.171 mg/m³ respectively 0.117 mg/m³ at zero and 0.317 mg/m³ respectively 0.297 mg/m³ at span point within the minimum requirements of VDI 4202.	yes	41
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	43
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	46
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	49
5.2.9 Drift of zero point	In 24 hours and in the maintenance interval maximum B_0.	In Figure 8 and Figure 9 is to be seen, that the zero point drifts meets the minimum requirements.	yes	52

Minimum requirement	Requirement	Test results	ful-filled?	Page
5.2.10 Drift of the measured value	In 24 hours and in the maintenance interval maximum 5 % of B1.	In Figure 10 and Figure 11 is to be seen, that the span point drift meets the minimum requirements.	yes	55
5.2.11 Cross-sensitivities	At the zero point maximum B0 and at the B2 level maximum 3 % of B2.	The cross-sensitivities of the measuring systems fulfil the minimum requirements.	yes	58
5.2.12 Reproducibility RD	RD ≥ 10 based on B1.	The minimum value of 10 for the reproducibility RD required by the VDI 4202 part 1 is exceeded clearly. Thus the minimum standards are kept.	yes	63
5.2.13 Hourly averages	Creation must be possible.	The measuring equipment allows the formation of one-hour mean values.	yes	65
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 and the mains frequency. The minimum requirements are fallen below clearly.	yes	69
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	70
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	71
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	72
5.2.18 Availability	Minimum 90 %.	The availability is higher than 90 %, so that the minimum requirement is fulfilled.	yes	74
5.2.19 Efficiency of the converter	Minimum 95 %.	not applicable.	Not applicable	75
5.2.20 Maintenance interval	If possible 28 days, minimum 14 days.	According to the requirements of the VDI 4202 part 1, the measuring equipment can be awarded with the present results the maximum possible at a field testing-period of 3 months with a maintenance interval of 1 month.	yes	77

Minimum requirement		Requirement	Test results	ful-filled?	Page
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 maximum 8.64 % for single values and of maximum 6.07 % for average values.	yes	80
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	81

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 CO Analyser Model 48i. The test followed the guidelines for the minimum requirements according to VDI 4202 and EN 14626.

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 14626. Therefore the measuring system was tested in the following measuring ranges:

Table 1: Tested components and measuring ranges

Component		Measuring range		
Carbon monoxide	CO	60	mg/m³	VDI 4202 part. 1
Carbon monoxide	CO	100	mg/m³	EN 14626

3 Description of the tested system

3.1 Measuring principle

The CO analyser Model 48i measures the CO concentration based on the gas filter correlation method. The analyser operates on the principle that carbon monoxide (CO) absorbs infrared radiation at a wavelength of 4.6 microns. The measuring system belongs to the group of photometric analysers. The principle is based on measuring the light absorption through the measuring gas in a for the gas characteristic wavelength range for the gas component to be detected. The evaluation is done by measuring the absorption based on the dependence between gas concentration and the amount of absorbed light and follows the law of Lambert-Beer:

$$I = I_0 * e^{-\alpha L c}$$

I_o Light intensity without absorption
I Intensity with absorption
L Absorption path or distance, which the light passes during the absorption
c Concentration of the absorbing gas component, in this case CO
α Absorption coefficient (provides information about the level of absorption)

Figure 1 shows the most important components of the analyser.

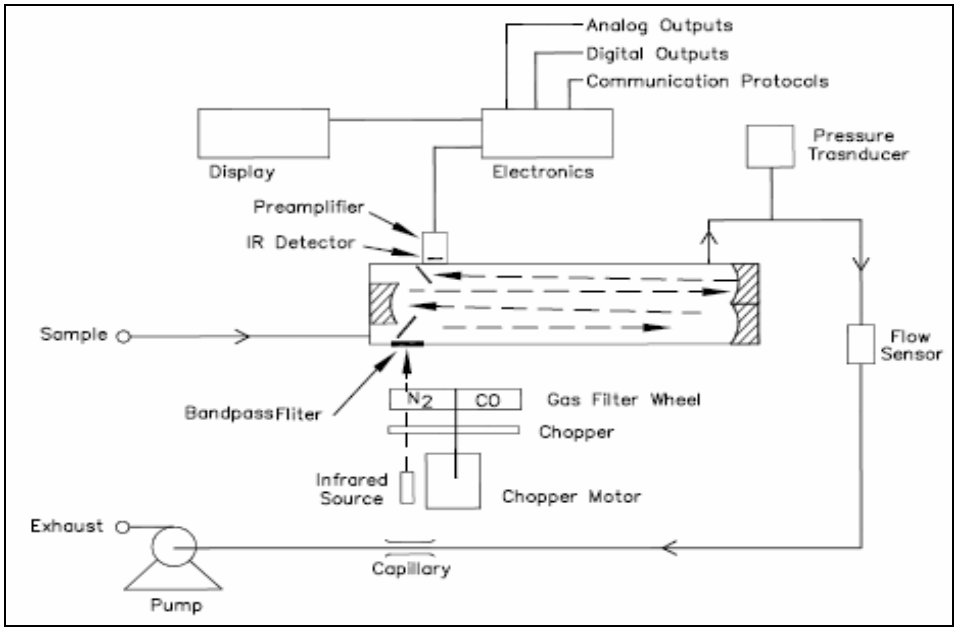


Figure 1: Model 48i – Scheme oft the measuring principle

The measuring principle is according to the reference method defined in the EN 14626.

3.2 Extent and set-up of the measuring system

The sample is drawn into the model 48i through the sample bulkhead, as shown in Figure 1. The sample flows through the optical bench. Radiation from an infrared source is chopped and then passed through a gas filter alternating between CO and N_2. The radiation then passes through a narrow band pass interference filter and enters the optical bench where absorption by the sample gas occurs. The infrared radiation then exits the optical bench and falls on an infrared detector.

The CO gas filter acts to produce a reference beam which cannot be further attenuated by CO in the sample cell. The N_2 side of the filter wheel is transparent to the infrared radiation and therefore produces a measure beam which can be absorbed in the cell. The chopped detector signal is modulated by the alternation between two gas filters with a amplitude related to the concentration of CO in the sample cell. Other gases do not cause modulation of the detector signal since they absorb the reference and measure beams equally. Thus, the GFC system responds specially to CO.

The Model 48i outputs the CO concentration to the front panel display, the analogue outputs, and also makes the data available over the serial or Ethernet connections.

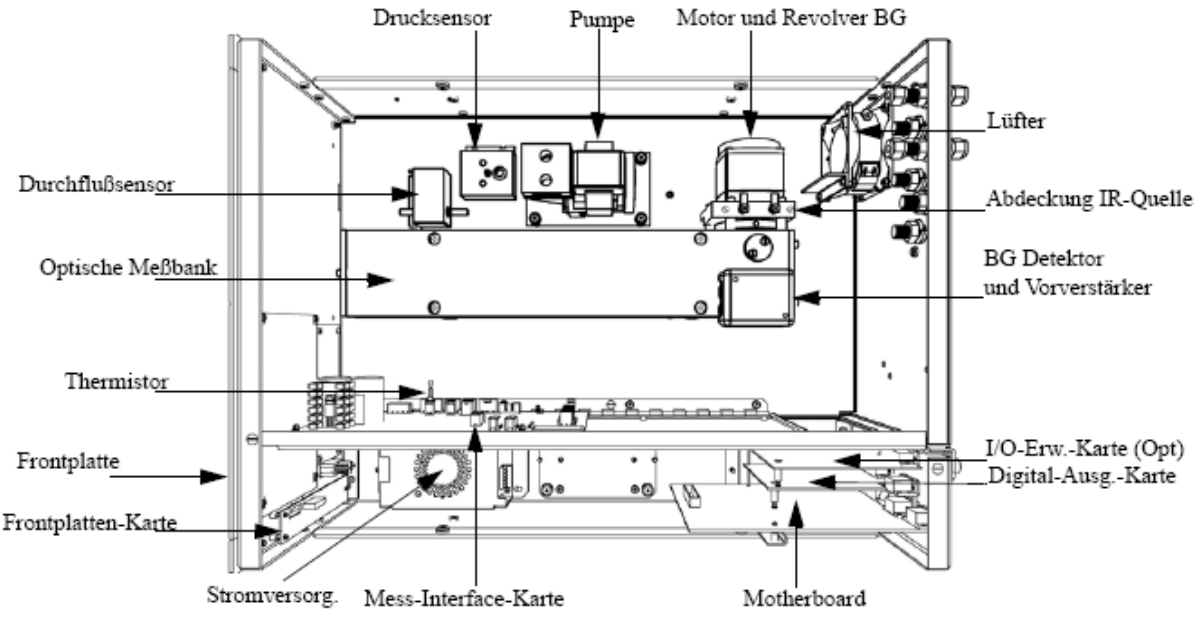


Figure 2: Hardware of the analyser model 48i

4 Test Program

4.1 Laboratory test

According to the guidelines the following test program arose 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

The lab test has been done with two identical analysers of the type CO Analyser Model 48i with the following serial numbers:

Unit 1: 48i – PTR - 01

Unit 2: 48i – PTR - 02

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 endurance test took place from 19.09.2005 to 19.12.2005. The analysers had during this period the following configuration:

Component		Measuring range	
Carbon monoxide	CO	0 - 100	mg/m³

The evaluation based on the in Table 1 mentioned certification interval.

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

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.

The following analysers have been tested:

Unit 1: 48i – PTR - 01

Unit 2: 48i – PTR - 02

5 Reference method

5.1 Component carbon monoxide

During the laboratory test as well as in the field test the application of test gases to the instruments was made using certified gases in gas cylinders, that were diluted by mass-flow controllers. The concentrations of the un-diluted test gases as well as the various concentration stages of the diluted gases were checked using the gas-chromatic method according to the Guideline VDI 2459, Vol. 1 “Measuring of gaseous Emissions – measuring of carbon-monoxide concentrations using a flame-ionisation detector (FID) after the reduction to methane”. The results of the analyses are given in Table 2.

The calibration of the gas-chromatograph was made by periodic injection according to Guideline VDI 3490, Vol. 7. For the generation of test-gases a dosing pump TELAB Type BF 411/30 was used. The TELAB – station was operated using a 100% CO test gas and Nitrogen for the dilution. Additional comparison analyses were made for further validation of the results using the Iodium-pentoxid-method according to Guideline VDI 2459 Vol.7.

Table 2: Results of the analyses of the test gases applied

Nominal value mg/m³	Actual value mg/m³	Deviation %
101.00	100.88	-0.12
90.90	90.58	-0.36
80.80	80.15	-0.80
70.70	70.00	-0.99
60.60	60.15	-0.74
50.50	50.30	-0.40
40.40	39.93	-1.18
30.30	30.09	-0.70
20.20	19.96	-1.18
10.10	9.98	-1.24
0.00	0.13	0.00

5.2 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).

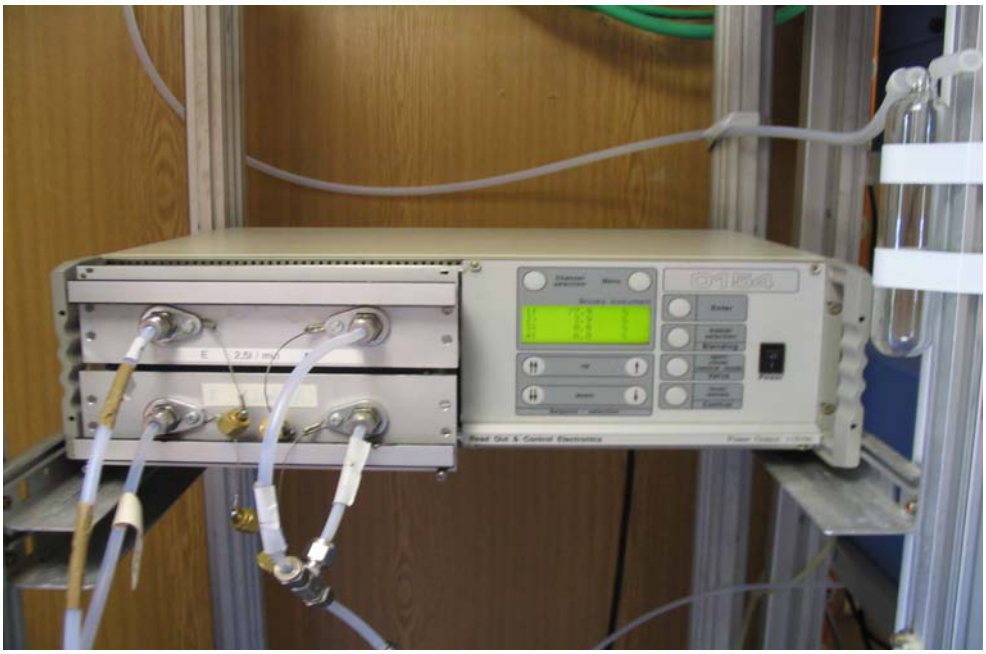


Figure 4: Test gas application by mass-flow controllers

5.3 Used test gases

During the tests for adjusting the monitors (units under test and TÜV-monitors) test gases were used additionally to the reference method sampling. The test gases listed were applied during the entire test and were diluted if required by a mass-flow controller resp. a gas divider.

Zero gas:	Nitrogen N_2
Test gas CO:	99,1 mg/m³ , 234 mg/m³ in N_2
No. of cylinder:	10274 (Lab), 10358 (Field)
Manufacturer / date of creation:	Praxair
Stability guarantee / certified	36 month
Check of certificate through:	TÜV laboratory, GC-method according to VDI 2459, part 1
Rel. uncertainty according certificate:	± 2 %

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 the display of the measured value can bee seen.

Figure 5: Front-view of the analyser

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 minutes has been defined.

The warm-up time is specified in the manual with 90 minutes. 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.

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 Metratester 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 3.

Table 3: Data of the analyser Thermo 48i

Instrument shape	built-in type
Mounting position	horizontal
Sample flow rate	1 liters/min.
Operating temperature	20 – 30 °C (electric secure use in the band 0-45 °C) in not condensing environment
Dimensions (H x B x T)	425.5 mm x 218.9 mm x 584.2 mm
Weight	23 kg
Power requirements	100 VAC @ 50/60 Hz 115 VAC @ 50/60 Hz 220-240 VAC @ 50/60 Hz 275 watts
Analogue 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 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 01.02.14.097

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 4 have been found.

Table 4: Test of the power consumption during regular operation

	Current consumption [A]	**Power consumption [W]**
Unit 1	1.10	253
Unit 2	1.09	251

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 (60mg/m³).

EN 14626: Certification-range 0 – 100 mg/m³ (corresponds 86 ppm)

6.2 Equipmnet

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 0-1 ppm and 0-1,000 ppm freely. It is possible, to indicate the measurement result on the display in different units (for example [ppm], [mg/m³]).

6.5 Assessment

The measuring ranges can be chosen optional according to the requirements. Also the measuring range requirements are kept according to EN 14626.

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 carbon monoxide 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 carbon monoxide 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 5: Overview of the life zero

	Minimum display field	Maximum display field
Unit 1	-0.59 Volt	11.61 Volt
Unit 2	-0.61 Volt	11.63 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 carbon monoxide concentrations were generated by means of a mass gas-flow controller. The concentration of the test gas in the cylinder was 99.1 mg/m³, the dilution was made by synthetic air.

6.3 Testing

The examination was made by application of graded carbon monoxide concentrations to the measuring system to be tested by means of dilution equipment.

6.4 Evaluation

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

$$Y = m * x + b$$

were determined through linear regression and subsequently are given in Table 6 and Table 7 for the five calibrating-cycles together with the coefficients of correlation.

Table 6: Individual results of the 5 series of experiments for the determination of the calibrating-function

Unit 1					
Number	**1**	**2**	**3**	**4**	**5**
Slope m [(mg/m³)/(mg/m³)]	0.9982	0.9977	0.9973	0.9977	1.001
Intercept of the axis b [mg/m³]	0.0784	0.1354	0.1500	0.1157	-0.0523
Correlation coefficient	1	1	1	1	1

Unit 2					
Number	**1**	**2**	**3**	**4**	**5**
Slope m [(mg/m³)/(mg/m³)]	1.0027	1.0039	1.0059	1.0018	1.0047
Intercept of the axis b [mg/m³]	-0.1466	-0.1889	-0.2862	0.0594	-0.2774
Correlation coefficient	1	1	1	1	1

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

$$X = 1/m * y - b/m$$

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

Table 7: Individual results of the 5 series of experiments for the determination of the analytical function

Unit 1					
Number	**1**	**2**	**3**	**4**	**5**
Slope 1/m [(mg/m³)/(mg/m³)]	1.0018	1.0023	1.0027	1.0023	0.9990
Intercept of the axis b/m [mg/m³]	0.0785	0.1357	0.1504	0.1160	-0.0522

Unit 2

Number	**1**	**2**	**3**	**4**	**5**
Slope 1/m [(mg/m³)/(mg/m³)]	0.9973	0.9961	0.9941	0.9982	0.9953
Intercept of the axis b/m [mg/m³]	-0.1462	-0.1882	-0.2845	0.0593	-0.2761

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 47 to Table 51 in the appendix. A graphical representation can be taken from Figure 6 and from Figure 7.

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 14626: 8.4.6 „lack of fit" (Deviation of linear regression)
0.20 µmol/mol (corresponds to 0.2 ppm or 0.232 mg/m³) at the zero point and ≤ 4 % of the measured value at the reference point.

6.2 Equipment

Different carbon monoxide concentrations were made using a mass flow controller. The concentration of the test gas in the cylinder was 99.1 mg/m³, the dilution was done by nitrogen.

6.3 Testing

The examination was made by application of graded carbon monoxide concentrations to the measuring system to be tested by means of dilution equipment analogously to the examination of the analytical function. The results were evaluated according to the rules of the linearity check.

The guideline VDI 4203 part 3 as well as the EN 14626 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 - 60 mg/m³ as well as for the range 0- 100 mg/m³ 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 a maximum deviation for values between zero and B_1 of 0.07 mg/m³ respectively -0.15 mg/m³ and a maximum deviation for values between zero and B_2 of 0.32 mg/m³ respectively -0.16 mg/m³ were derived. The detailed results of the investigations can be found in Table 8 and Table 9.

Regarding the EN 14626 criteria's the following results have been determined:

For device 1 a deviation from the linear regression line of 0.01 mg/m³ (equivalent to 0.01 ppm) at zero and maximum 0.81 % of measured value at a concentrations higher than zero could be determined.

For device 2 a deviation from the linear regression line of -0.15 mg/m³ (equivalent to -0.13 ppm) at zero and maximum -0.71 % of measured value at a concentrations higher than zero could be determined.

Table 8: Linearity Thermo 48i from group mean values, device 1

Test gas value [mg/m³]	Measuring [mg/m³]	Deviation [mg/m³]	Allowed deviation VDI 4202 [mg/m³]	Allowed deviation EN 14626 [mg/m³]	Deviation [% of measured value]
0,00	0,01	0,01	1,0	0,2	-----
9,91	9,98	0,07	1,0	0,4	0,71
19,82	19,84	0,02	1,0	0,8	0,10
29,73	29,82	0,09	0,6	1,2	0,30
39,64	39,96	0,32	0,6	1,6	0,81
49,55	49,68	0,13	0,6	2,0	0,26
59,46	59,14	-0,32	0,6	2,4	-0,54
69,37	69,26	-0,11	0,6	2,8	-0,16
79,28	79,10	-0,18	0,6	3,2	-0,23
89,19	89,12	-0,07	0,6	3,6	-0,08
99,10	99,20	0,10	0,6	4,0	0,10

Table 9: Linearity Thermo 48i from group mean values, device 2

Test gas value [mg/m³]	Measuring [mg/m³]	Deviation [mg/m³]	Allowed deviation VDI 4202 [mg/m³]	Allowed deviation EN 14626 [mg/m³]	Deviation [% of measured value]
0,00	-0,15	-0,15	1,0	0,2	-----
9,91	9,84	-0,07	1,0	0,4	-0,71
19,82	19,75	-0,07	1,0	0,8	-0,35
29,73	29,62	-0,11	0,6	1,2	-0,37
39,64	39,48	-0,16	0,6	1,6	-0,40
49,55	49,56	0,01	0,6	2,0	0,02
59,46	59,58	0,12	0,6	2,4	0,20
69,37	69,50	0,13	0,6	2,8	0,19
79,28	79,40	0,12	0,6	3,2	0,15
89,19	89,38	0,19	0,6	3,6	0,21
99,10	99,30	0,20	0,6	4,0	0,20

6.5 Assessment

As given in Table 8 and Table 9, the two candidates meet the requirements of the guideline of VDI 4202 and the EN 14626 in full extent.

Minimum requirement fulfilled? yes

6.6 Documentation

In Table 10 and Table 11 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 47 to Table 51.

Table 10: Statistical characteristics on basis of the group mean values for device 1

Characteristics device 1				
Standard deviation	s	=	0.172	
Coefficient of correlation	r	=	1.0000	
Y = b* x + c Slope	b	=	0.998	
Intercept	c	=	0.085	mg/m³
Mean value	Measuring value	=	49.6	mg/m³
Mean value	Expected value	=	49.6	mg/m³

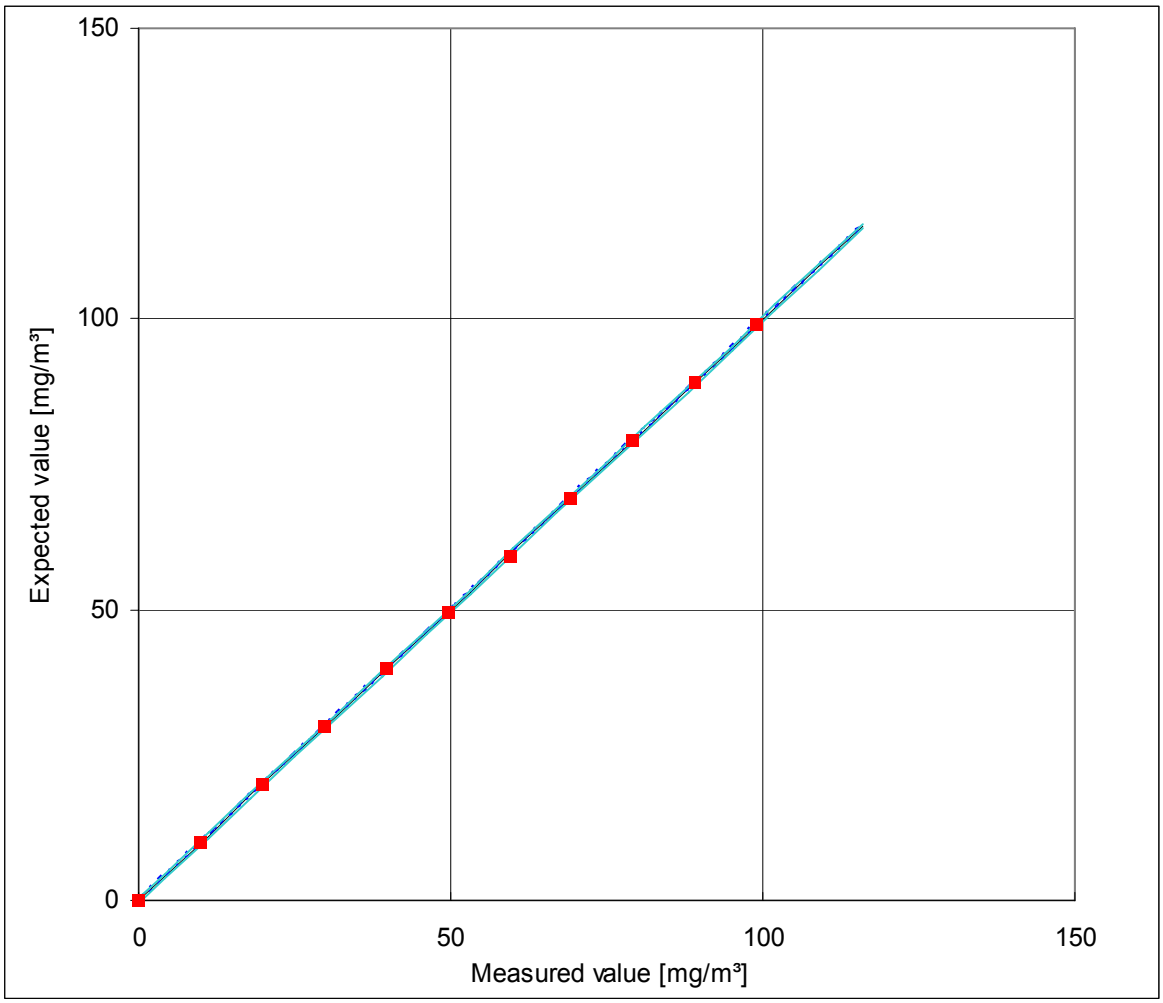


Figure 6: Analytical function from the group mean values for device 1

Table 11: Statistical characteristics on basis of the group mean values for device 2

Characteristics device 2				
Standard deviation	s	=	0.061	
Coefficient of correlation	r	=	1.0000	
Y = b* x + c Slope	b	=	1.004	
Intercept	c	=	-0.168	mg/m³
Mean value	Measuring value	=	49.6	mg/m³
Mean value	Expected value	=	49.6	mg/m³

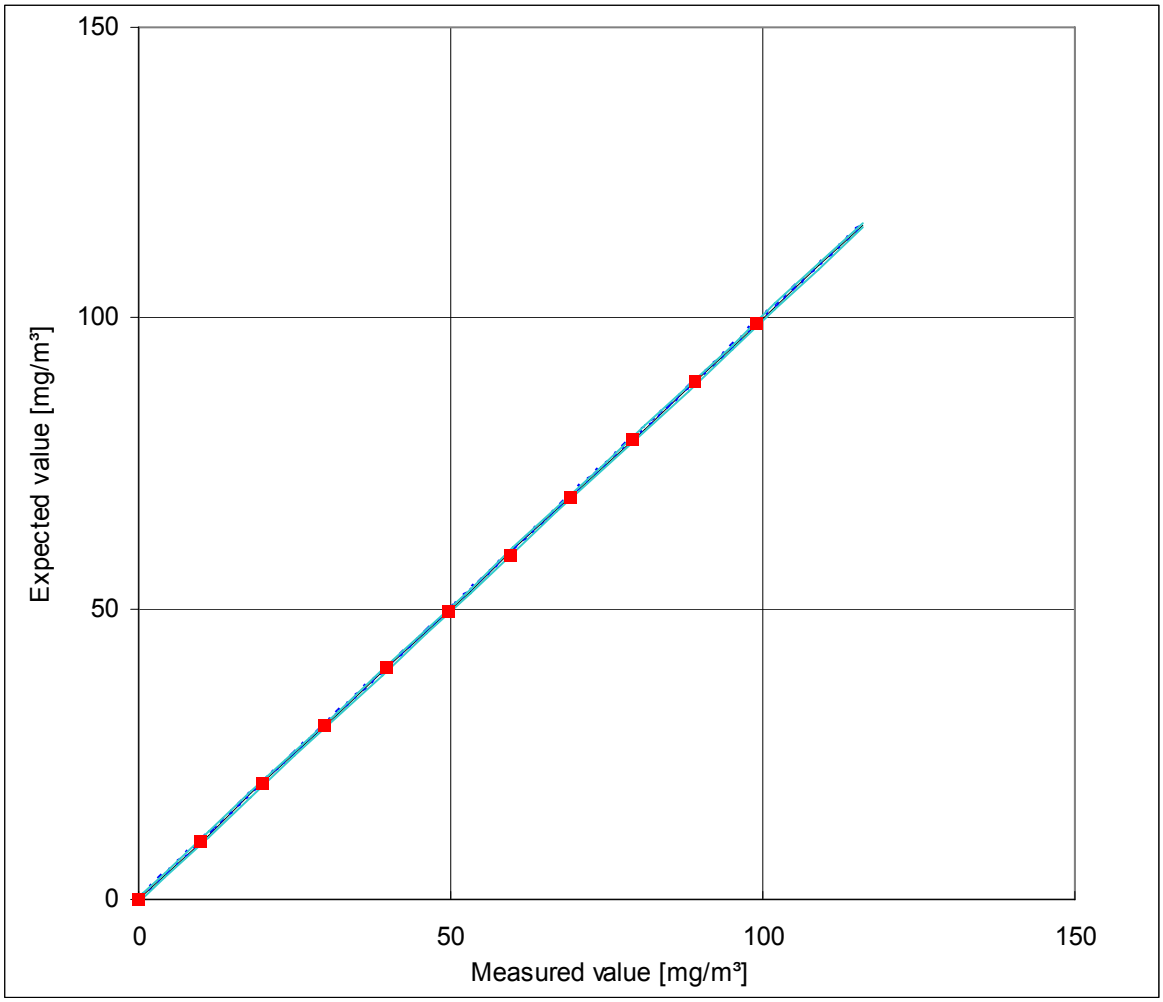


Figure 7: Analytical function from the group mean values for device 2

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 14626: 8.4.5 repeating standard deviation at zero ≤ 1.0 µmol/mol ((corresponds to 1 ppm or 1.16 mg/m³); am Ref.-Pkt. ≤ 3.0 µmol/mol ((corresponds to 3 ppm or 3.48 mg/m³)

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 14626 for the determination of the detection limit 20 measured values each are necessary. The EN 14626 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 = 1 mg/m³. The Table 12 and Table 13 show in conclusion the results of the investigations. According to the requirements of the VDI the detection limit is defined as 3* standard deviation (VDI 2449 part 1).

The repeating standard deviation of this measurement demanded for in EN 14626 is calculated as follows:

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

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

Table 12: Survey of the detection limits Thermo 48i device 1

Measuring		Zero point		Span point	
		Lab	Field	Lab	Field
		mg/m³	mg/m³	mg/m³	mg/m³
Number	n	20	15	20	15
Mean value	x	0.262	0.142	48.50	53.80
Repeating standard deviation	**s_r**	**0.057**	**0.0280**	**0.088**	**0.106**
DL = 3 * standard deviation	**3*s**	**0.171**	**0.083**	**0.265**	**0.317**
Requirements of VDI 4202	mg/m³	1	1	1	1
Met requirements?		**yes**	**yes**	**yes**	**yes**
Requirements of EN 14626	mg/m³	1.16	----	3.48	----
Met requirements?		**yes**	**----**	**yes**	**----**

Table 13: Survey of the detection limits Thermo 48i device 2

Measuring		Zero point		Span point	
		Lab	Field	Lab	Field
		mg/m³	mg/m³	mg/m³	mg/m³
Number	n	20	15	20	15
Mean value	x	0.126	0.122	47.60	53.80
Repeating standard deviation	**s_r**	**0.088**	**0.039**	**0.093**	**0.099**
DL = 3 * standard deviation	**3*s**	**0.090**	**0.117**	**0.280**	**0.297**
Requirements of VDI 4202	mg/m³	1	1	1	1
Met requirements?		**yes**	**yes**	**yes**	**yes**
Requirements of EN 14626	mg/m³	1.16	----	3.48	----
Met requirements?		**yes**	**----**	**yes**	**----**

6.5 Assessment

The detection limit is with 0.171 mg/m³ respectively 0.117 mg/m³ at zero and 0.317 mg/m³ respectively 0.297 mg/m³ at span point within the minimum requirements of VDI 4202.

The determined repeating standard deviation of EN 14626 is 0.057 mg/m³ (equal to 0.049 ppm) respectively 0.088 mg/m³ (equal to 0.075 ppm) at zero and 0.088 mg/m³ (equal to 0.075 ppm) respectively 0.093 mg/m³ (equal to 0.080 ppm) at span.

Minimum requirement fulfilled? yes

6.6 Documentation

The individual results are given in the appendix in Table 52 and Table 53.

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 14626: 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 the table:

Table 14: Increasing and falling response times of the two measuring units

Start value [mg/m³]	Final value 90% [mg/m³]	Time unit 1 [s]	Time unit 2 [s]	Requirement according to VDI 4202 and EN 14626 [s]	Requirement fulfilled?
0	54	47	46	180	yes
60	6	54	54	180	yes
	Difference	**7**	**8**		
0	54	43	43	180	yes
60	6	50	50	180	yes
	Difference	**7**	**7**		
0	54	50	50	180	yes
60	6	55	55	180	yes
	Difference	**5**	**5**		
0	54	48	48	180	yes
60	6	51	51	180	yes
	Difference	**3**	**3**		

According to EN 14626 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)

For device 1 a maximum t_r of 50 s, a maximum t_f of 55 s and a t_d of 11.7 % has been calculated.
For device 2 a maximum t_r of 50 s, a maximum t_f of 55 s and a t_d of 12.3 % has been calculated.

A relative difference between rise and fall time of more than 10 % has been determined. The absolute difference is less than 10 seconds, so this requirement is 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 14626.

Minimum requirement fulfilled? yes

6.6 Documentation

The test results are given in Table 14.

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 14626: 8.4.9 Sensitivity coefficient of the ambient temperature
≤ 0.30 µmol/mol/K (corresponds to 0.3 ppm/K or 0.35 (mg/m³)/K)

6.2 Equipment

Climate chamber.

6.3 Testing

According to VDI 4202 part 1 the temperature dependence of the zero point 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 14626 demands for an examination 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

At every temperature level the deviations were determined to the starting point at 20°C. For every temperature step the mean value was calculated and compared with the minimum requirements. The permissible deviation from the starting point must not exceed B_0 that is 1 mg/m³ at any temperature point.

Table 15: Mean values and evaluation of the temperature dependence according to VDI 4202, device 1

T [°C]	Mean value unit 1 [mg/m³]	Deviation to the mean value [mg/m³]	Allowed deviation [mg/m³]	Requirement fulfilled? VDI 4202
20	0.10	----	----	----
5	0.16	0.06	1	yes
20	0.10	----	----	----
40	-0.01	-0.11	1	yes
20	0.11	----	----	----

Table 16: Mean values and evaluation of the temperature dependence according to VDI 4202, device 2

T [°C]	Mean value unit 1 [mg/m³]	Deviation to the mean value [mg/m³]	Allowed deviation [mg/m³]	Requirement fulfilled? VDI 4202
20	0.13	----	----	----
5	0.22	0.09	1	yes
20	0.13	----	----	----
40	0.07	-0.06	1	yes
20	0.13	----	----	----

As Table 15 and Table 16 shows, the deviations are in the allowed limits. The greatest deviation of both devices -0.11 mg/m³ for device 1 and 0.09 mg/m³ for device 2 have been taken for the calculation of total uncertainty of VDI 4202.

Following EN 14626 the sensitivity coefficient of the ambient temperature must not exceed 0.35 mg/m³ per K temperature change.

The sensitivity coefficient 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/m³)

x_T the mean value of the measurements at T_{min} or T_{max} (mg/m³)

x_1 the first mean value of the measurements at T_1 (mg/m³)

x_2 the second mean value of the measurements at T_1 (mg/m³)

T_1 the ambient air temperature in the lab (K)

T the ambient air temperature T_{min} or T_{max} (K)

Table 17: Sensitivity coefficient of the ambient temperature at the zero point according to EN 14626, device 1

	T [°C]	Mean value unit 1 [mg/m³]	determinated b_{st} [mg/m³]/K	allowed b_{st} [mg/m³]/K	Fulfilled ? EN 14626
T_1	20	0.10			
T_{min}	0	0.19	0.004	0.35	ja
T_1	20	0.11			
T_1	20	0.11			
T_{max}	30	-0.01	0.012	0.35	ja
T_1	20	0.10			

Table 18: Sensitivity coefficient of the ambient temperature at the zero point according to EN 14626, device 2

	T [°C]	Mean value unit 2 [mg/m³]	determinated b_{st} [mg/m³]/K	allowed b_{st} [mg/m³]/K	Fulfilled ? EN 14626
T_1	20	0.13			
T_{min}	0	0.23	0.005	0.35	ja
T_1	20	0.13			
T_1	20	0.13			
T_{max}	30	0.07	0.006	0.35	ja
T_1	20	0.13			

As to see into Table 17 and Table 18, the sensitivity coefficient of the ambient temperature fulfills the performance requirements at the zero point.

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 14626.

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 14626 are fulfilled as well.

Minimum requirement fulfilled? yes

6.6 Documentation

The single data of the investigations are to be taken from the appendix in Table 54.

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 shalle 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 14626: 8.4.9 Sensitivity coefficient of the ambient temperature ≤ 0.30 µmol/mol/K (corresponds to 0.30 ppm/K or 0.35 (mg/m³)/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. 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.

The concentration of the test gas is about B_1 (B_1 = 20 mg/m³).

Differing from that the EN 14626 demands for an examination 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.

The test gas concentration is between 70 - 80 % of the certificated range (approx. 80 mg/m³).

6.4 Evaluation

At every temperature level the deviations were determined to the starting point at 20°C. For every temperature step the mean value was calculated and compared with the minimum requirements. The permissible deviation from the starting point must not exceed 5 % of B_1 (1 mg/m³) at any temperature point.

Table 19: Mean values and evaluation of the temperature dependence of the span point according to VDI 4202, device 1

T [°C]	Mean value unit 1 [mg/m³]	Deviation to the mean value [mg/m³]	Allowed deviation [mg/m³]	Requirement fulfilled? VDI 4202
20	20.24	----	----	----
5	20.97	0.73	1	yes
20	21.22	----	----	----
40	21.04	-0.18	1	yes
20	21.22	----	----	----

Table 20: Mean values and evaluation of the temperature dependence of the span point according to VDI 4202, device 2

T [°C]	Mean value unit 2 [mg/m³]	Deviation to the mean value [mg/m³]	Allowed deviation [mg/m³]	Requirement fulfilled? VDI 4202
20	21.21	----	----	----
5	21.49	0.28	1	yes
20	21.20	----	----	----
40	20.96	-0.24	1	yes
20	21.14	----	----	----

As given in Table 19 and Table 20 the allowed deviations at the span point are in the limits. The greatest deviation of both devices 0.73 mg/m³ for device 1 and 0.28 mg/m³ for device 2 have been taken for the calculation of total uncertainty of VDI 4202.

Following EN 14626 the sensitivity coefficient of the ambient temperature must not exceed 0.35 mg/m³ per K temperature change.

The sensitivity coefficient 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/m³)

x_T the mean value of the measurements at T_{min} or T_{max} (mg/m³)

x_1 the first mean value of the measurements at T_1 (mg/m³)

x_2 the second mean value of the measurements at T_1 (mg/m³)

T_1 the ambient air temperature in the lab (K)

T the ambient air temperature T_{min} or T_{max} (K)

Table 21: Sensitivity coefficient of the ambient temperature at the span point according to EN 14626, device 1

	T [°C]	Mean value unit 1 [mg/m³]	determinated b_{st} [mg/m³]/K	allowed b_{st} [mg/m³]/K	Fulfilled ? EN 14626
T_1	20	75.70			
T_{min}	0	74.88	0.04	0.35	yes
T_1	20	75.69			
T_1	20	75.69			
T_{max}	30	75.33	0.04	0.35	yes
T_1	20	75.78			

Table 22: Sensitivity coefficient of the ambient temperature at the span point according to EN 14626, device 2

	T [°C]	Mean value unit 1 [mg/m³]	determinated b_{st} [mg/m³]/K	allowed b_{st} [mg/m³]/K	Fulfilled ? EN 14626
T_1	20	75.60			
T_{min}	0	76.24	0.03	0.35	yes
T_1	20	75.60			
T_1	20	75.60			
T_{max}	30	75.87	0.03	0.35	yes
T_1	20	75.60			

As to see in Table 21 and Table 22, the sensitivity coefficient of the ambient temperature fulfils the performance requirements at the span point. 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 14626.

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 14626 is also fulfilled.

Minimum requirement fulfilled? yes

6.6 Documentation

The single dates of the investigations are to be taken from the appendix in Table 55 and Table 56.

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 14626: 8.4.4 Short term drift at zero ≤ 0,10 µmol/mol/12h (corresponds to 0,1 ppm/12h or 0,116 (mg/m³)/12h)

EN 14626: 6.5.4 Long term drift at zero ≤ 0,50 µmol/mol (corresponds to 0,58 mg/m³)

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.

6.4 Evaluation

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

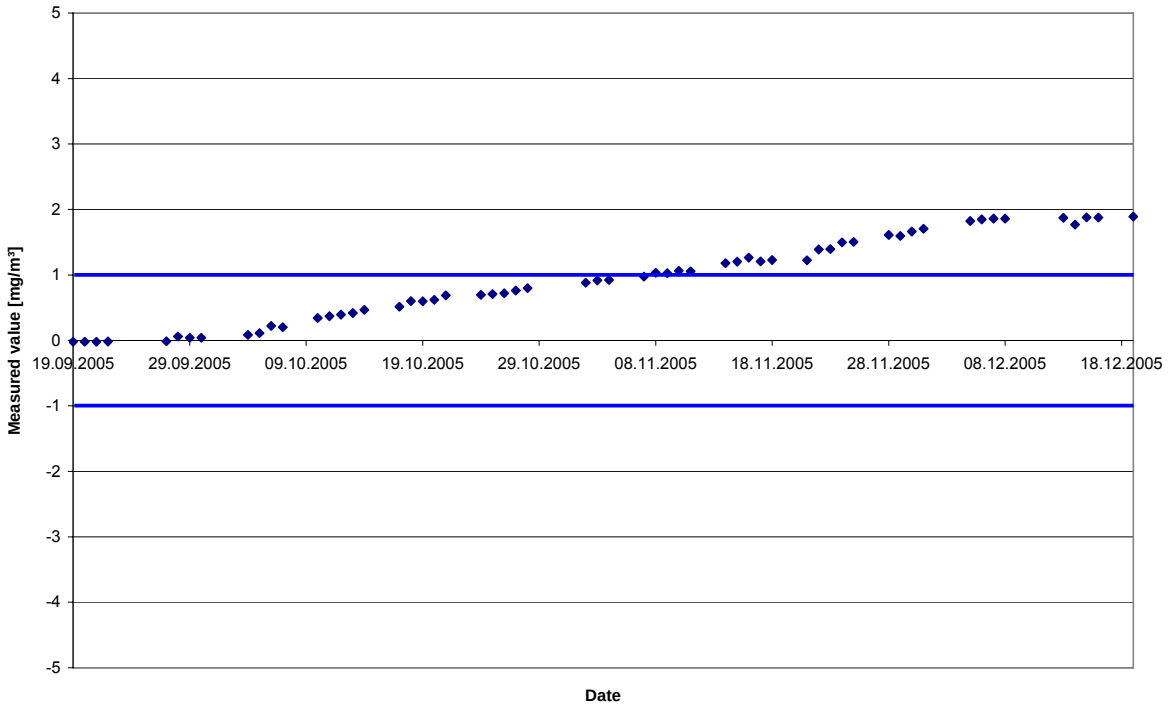


Figure 8: Temporal change of the zero points during the field test, unit 1

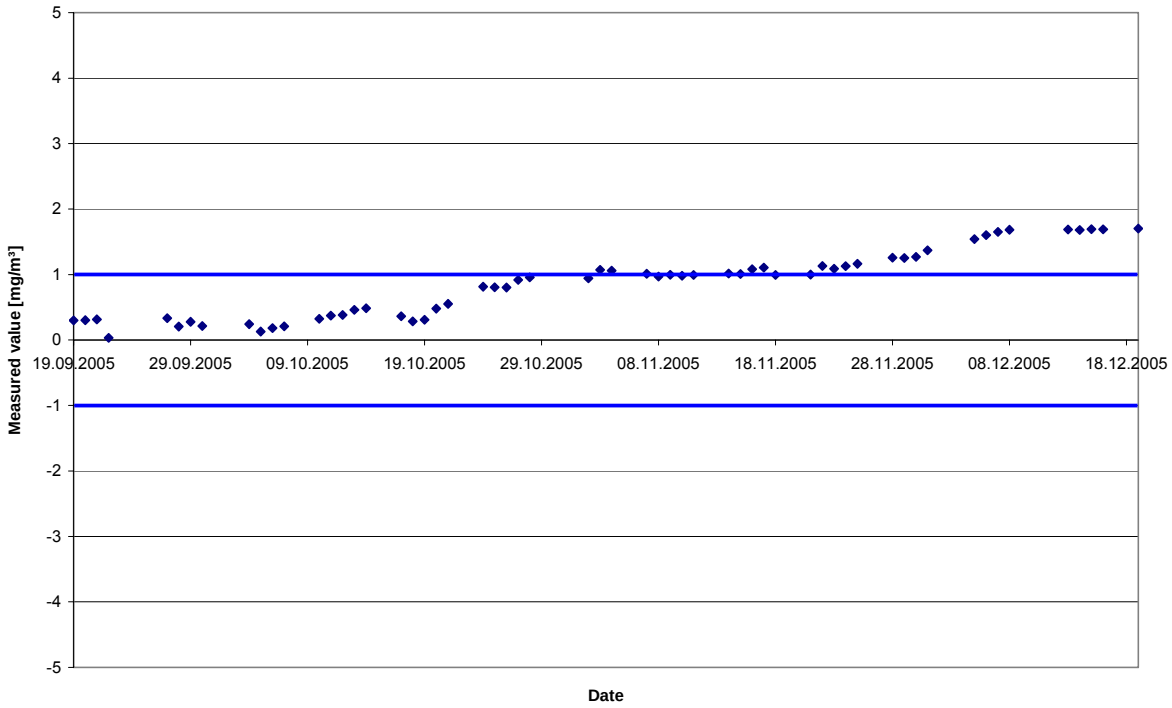


Figure 9: Temporal change of the zero points during the field test, unit 2

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 B_0 (corresponds 1 mg/m³ for CO). 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:

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

Unit 1: 0.024 mg/(m³*d)

Unit 2: 0.018 mg/(m³*d)

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

Unit 1: 0.72 mg/(m³*month) equal to 0.62 ppm/month

Unit 2: 0.55 mg/(m³*month) equal to 0.47 ppm/month

At a maintenance interval of four weeks the allowed drift may be 1 mg/(m³*month), the investigations have shown a monthly drift of 0.72 mg/m³.

Thus the minimum requirements are kept surely.

Following the EN 14626 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.

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/m³)

$C_{Z,1}$ the mean of the zero gas measurement at the beginning of the drift period (mg/m³)

$C_{Z,2}$ the mean of the zero gas measurement at the end of the drift period (mg/m³)

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

Unit 1: 0.00 (mg/m³)/12 h equal to 0.00 ppm/12h

Unit 2: 0.00 (mg/m³)/12 h equal to 0.00 ppm/12h

6.5 Assessment

In Figure 8 and Figure 9 is to be seen, that the zero point drifts meets the minimum requirements. It is over the three month field test duration 0.72 mg/(m³*month). Also the short-term drift of the EN 14626 fulfils the required criterion.
For the examined period of one month, the requirement of the long-term drift to EN 14626 is outside of the allowed limits for device 1 and inside for device 2.

Minimum requirement fulfilled? yes

6.6 Documentation

See Figure 8 and Figure 9. The single values of the short term drift according to EN 14626 are shown in Table 57 and in Table 58 in the appendix.

6.1 5.2.10 Drift of the 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 14626: 8.4.4 Short term drift at span level ≤ 0.60 µmol/mol/12h (corresponds to 0.6 ppm/12h or 0.696 (mg/m³)/12h.
EN 14626: 8.5.4 Long term drift at span level ≤ 5 % of the measuring range (corresponds to 5 mg/m³ at a range of 0 to 100 mg/m³).

6.2 Equipment

For the determination of the span point drift a test gas out of cylinders has been used.

6.3 Testing

The offering of test gas was made over a period of 15 minutes daily. The last 5 minutes of this time interval were recorded, averaged and evaluated.

6.4 Evaluation

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

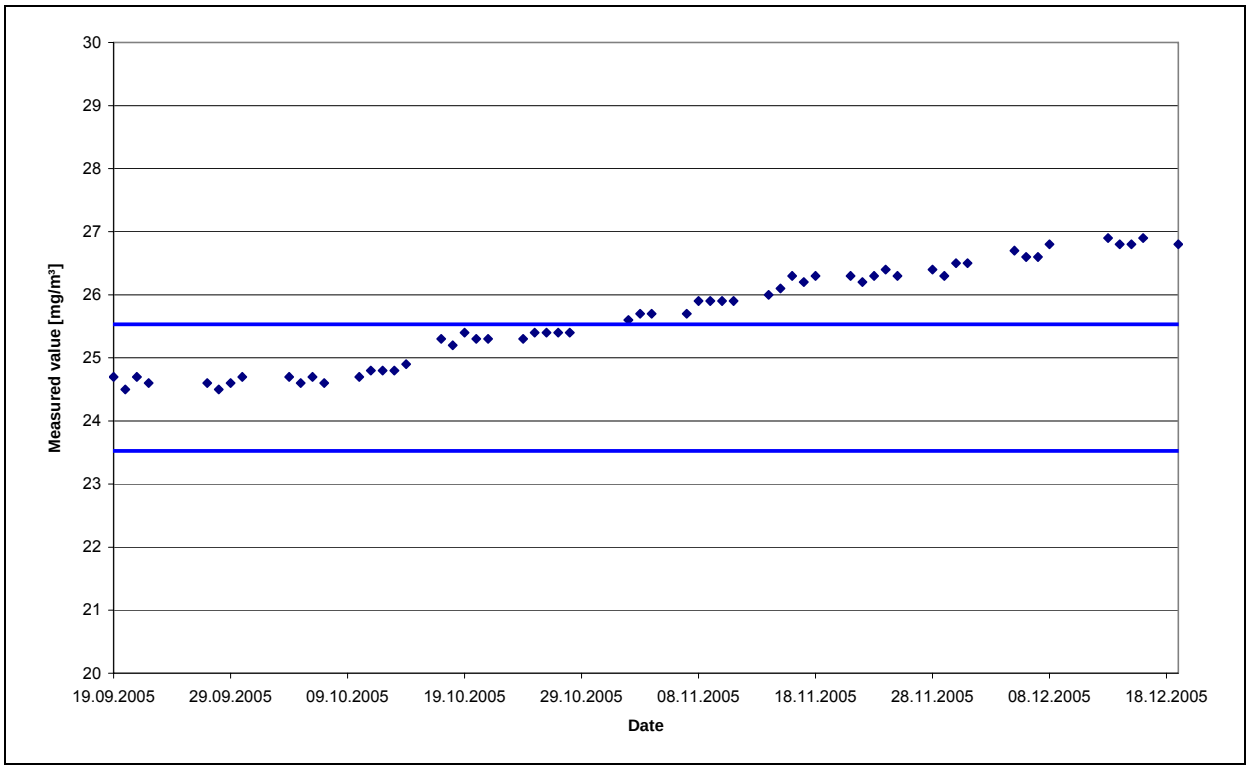


Figure 10: Temporal change of the span points during the field test, unit 1

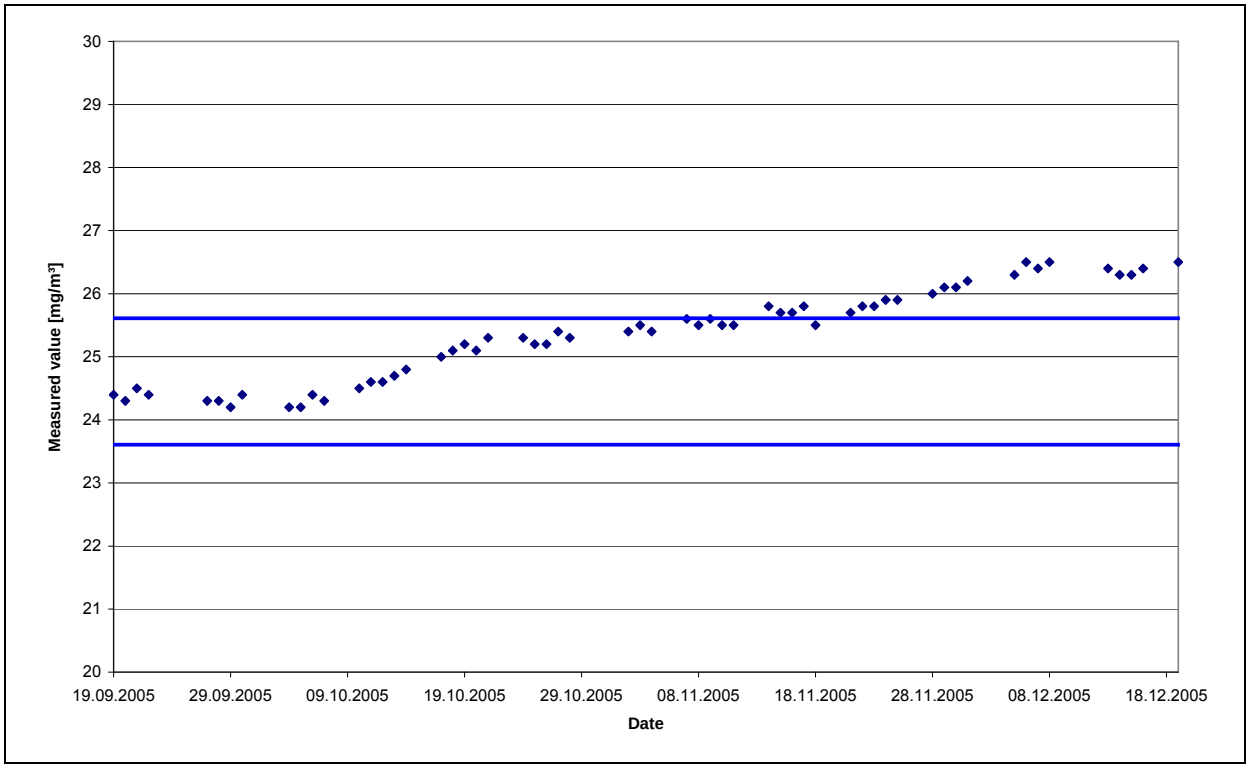


Figure 11: Temporal change of the span points during the field test, unit 2

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 B_1 (corresponds 1 mg/m³ for CO).

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:

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

Unit 1: 0.029 mg/(m³*d)

Unit 2: 0.027 mg/(m³*d)

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

Unit 1: 0.87 mg/(m³*month) equal to 0.75 ppm/month

Unit 2: 0.81 mg/(m³*month) equal to 0.70 ppm/month

At a maintenance interval of four weeks the allowed drift may be 1 mg/(m³*month), the investigations have shown a monthly drift of 0.87 mg/m³ . Thus the minimum requirement is kept surely.

Following the EN 14626, the short-term drift in the lab is determined with in each case 20 single measurements before and after a 12 h duration of time.

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/m³)

$C_{S,1}$ the mean of the zero gas measurement at the beginning of the drift period (mg/m³)

$C_{S,2}$ the mean of the zero gas measurement at the end of the drift period (mg/m³)

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

Unit 1: 0.3 (mg/m³)/12 h equal to 0.26 ppm/12h

Unit 2: -0.1 (mg/m³)/12 h equal to -0.09 ppm/12h

6.5 Assessment

In Figure 10 and Figure 11 is to be seen, that the span point drift meets the minimum requirements. It shows 0,87 mg/(m³*month) for the three month field test duration. Also the short-term drift of the EN 14626 fulfils the required criterion. The requirement of the long-term drift to EN 14626 is in the allowed limits.

Minimum requirement fulfilled? yes

6.6 Documentation

See Figure 10 and Figure 11. The single values of the short term drift according to EN 14626 are shown in Table 57 and in Table 58 in the appendix.

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 14626 8.4.11 Interferences – allowed deviations for H_2O ≤ 1.0 µmol/mol (corresponds to 1 ppm or 1.16 mg/m³); or CO_2, NO, N_2O for each ≤ 0.5 µmol/mol (corresponds to 0.5 ppm or 0.58 mg/m³)

6.2 Equipment

Reference gases, mass-flow-controller

6.3 Testing

For the determination of the cross-sensitivities the components listed in Table 23 have been taken into account. On the basis of the measuring method additional components are considered.

Table 23: Interfering components and values

Interferent	Value
CO_2	700 mg/m³
CO	60 mg/m³
H_2O	30 % to 90 % relative humidity
SO_2	700 µg/m³
NO	100 µg/m³ to 1000 µg/m³
NO_2	400 µg/m³
N_2O	500 µg/m³
H_2S	30 µg/m³
NH_3	30 µg/m³
O_3	360 µg/m³
Benzene	1000 µg/m³

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 1 mg/m³ (B_0) and a deviation of 1.8 mg/m³ (3 % of B_2) at the span point.

Table 24: Cross-sensitivities Thermo 48i

Interferent			Analyser 1		Analyser 2	
			Deviation [mg/m³]		Deviation [mg/m³]	
			ZP	SP	ZP	SP
CO_2	700	mg/m³	0.00	0.00	0,02	-0,13
NO_2	400	µg/m³	0.00	0.07	0,00	-0,30
H_2O	80	rel.-%	0.20	-0.07	-0,18	0,00
SO_2	700	µg/m³	0.00	0.00	0,12	0,10
NO	1000	µg/m³	0.01	0.10	-0,01	-0,10
O_3	360	µg/m³	0.01	0.00	0,01	-0,13
N_2O	0,5	mg/m³	0.00	0.00	0,03	0,13
H_2S	30	µg/m³	0.00	0.00	-0,02	-0,07
NH_3	30	µg/m³	0.03	0.07	-0,06	-0,13
Benzol	1000	µg/m³	0.00	0.03	-0,01	-0,03
Sum of negative deviations			**-0,00**	**-0,07**	**-0.28**	**-0.89**
Sum of positive deviations			**0,25**	**0,27**	**0.18**	**0.23**
Allowed deviation [mg//m³]			**1**	**1,8**	**1**	**1,8**
Requirement fulfilled?			**yes**	**yes**	**yes**	**yes**

The summarized positive and negative deviations do not exceed the allowed minimum requirements. 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 0.27 m/m³ for device 1 und -0.89 mg/m³ for device 2.

Following the EN 14626 the measuring instruments must be checked only for cross-sensitivity to the components H_2O, CO_2, NO and N_2O.

Table 25 Interfering components according to EN 14626

Cross-sensitivity according to EN 14626			Unit 1		Unit 2	
			Deviation [mg/m³]		Deviation [mg/m³]	
			ZP	SP	ZP	SP
H_2O	80	rel-%	0.20	-0.07	-0,18	0,00
Maximum deviation			1.16	1.16	1.16	1.16
Fulfilled ?			**yes**	**yes**	**yes**	**yes**
CO_2	500	ppm	0.00	0.00	0,02	-0,13
Maximum deviation			0.58	0.58	0.58	0.58
Fulfilled ?			**yes**	**yes**	**yes**	**yes**
NO	1	ppm	0.01	0.10	-0,01	-0,10
Maximum deviation			0.58	0.58	0.58	0.58
Fulfilled ?			**yes**	**yes**	**yes**	**yes**
N_2O	0.05	ppb	0.00	0.00	0,03	0,13
Maximum deviation			0.58	0.58	0.58	0.58
Fulfilled ?			**yes**	**yes**	**yes**	**yes**

Regarding EN 14626 the following deviations in ppm have been determined:

Cross-sensitivity according to EN 14626			Unit 1		Unit 2	
			Deviation [ppm]		Deviation [ppm]	
			ZP	SP	ZP	SP
H_2O	80	rel-%	0.17	-0.06	-0,16	0,00
Maximum deviation			1.00	1.00	1.00	1.00
Fulfilled ?			**yes**	**yes**	**yes**	**yes**
CO_2	500	ppm	0.00	0.00	0,02	-0,11
Maximum deviation			0.50	0.50	0.50	0.50
Fulfilled ?			**yes**	**yes**	**yes**	**yes**
NO	1	ppm	0.01	0.09	-0,01	-0,09
Maximum deviation			0.50	0.50	0.50	0.50
Fulfilled ?			**yes**	**yes**	**yes**	**yes**
N_2O	0.05	ppb	0.00	0.00	0,03	0,11
Maximum deviation			0.50	0.50	0.50	0.50
Fulfilled ?			**yes**	**yes**	**yes**	**yes**

6.5 Assessment

The cross-sensitivities of the measuring systems fulfil the minimum requirements. As to see in Table 25, the requirements of the EN 14626 are kept for H_2O, CO_2, NO and N_2O as well.

Minimum requirement fulfilled? yes

6.6 Documentation

The single values are given in Table 59 to Table 62.

6.1 5.2.12 Reproducibility R_D

The reproducibility 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 14626: 8.5.5 Standard deviation under field conditions ≤ 5 % of the average over 3 month.

6.2 Equipment

In addition to the measuring system a CO test gas has been used for the enrichment of the sampled air.

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 in the field the data were selected from a level of 20 mg/m³ ± 20 %. Additionally the reproducibility 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.

Since in the ambient air the carbon monoxide concentrations usually are clearly below the B_1-value, an enrichment of the sucked air was carried out both in the field test and in the lab test on the sample gas inlet of the analyser. This enrichment was done through adding material of a raised carbon monoxide concentration by means of a mass flow controller.

6.4 Evaluation

The Table 29 shows the single values of the results achieved in the lab test. In Table 26 the statistical parameters of the evaluation are given.

Table 26: Evaluation of the reproducibility R_D in the lab test

Reproducibility in the lab test				
No. of values	n	=	10	
Reference value		=	20	mg/m³
t-value for the selected safety	t95	=	2.229	
Standard deviation out of parallel measurements	sd	=	0.314	
Reproducibility R_D	**R(d)**	**=**	**29**	
Mean value	Unit 1	=	20.7	mg/m³
Mean value	Unit 2	=	21.2	mg/m³

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

Table 27: Evaluation of the reproducibility R_D near B_1 in the field test

Reproducibility in the field test				
No. of values	n	=	34	
Reference value		=	20	mg/m
t-value for the selected safety	t95	=	2.032	
Standard deviation out of parallel measurements	sd	=	0.194	
Reproducibility R_D	**R(d)**	**=**	**51**	
Standard deviation	s	=	0.256	
Coefficient of correlation	r	=	0.9880	
Y = b* x + c Slope	b	=	1.041	
Intercept	c	=	-0.715	mg/m³
Mean value	Unit 1	=	19.713	mg/m³
Mean value	Unit 2	=	19.810	mg/m³

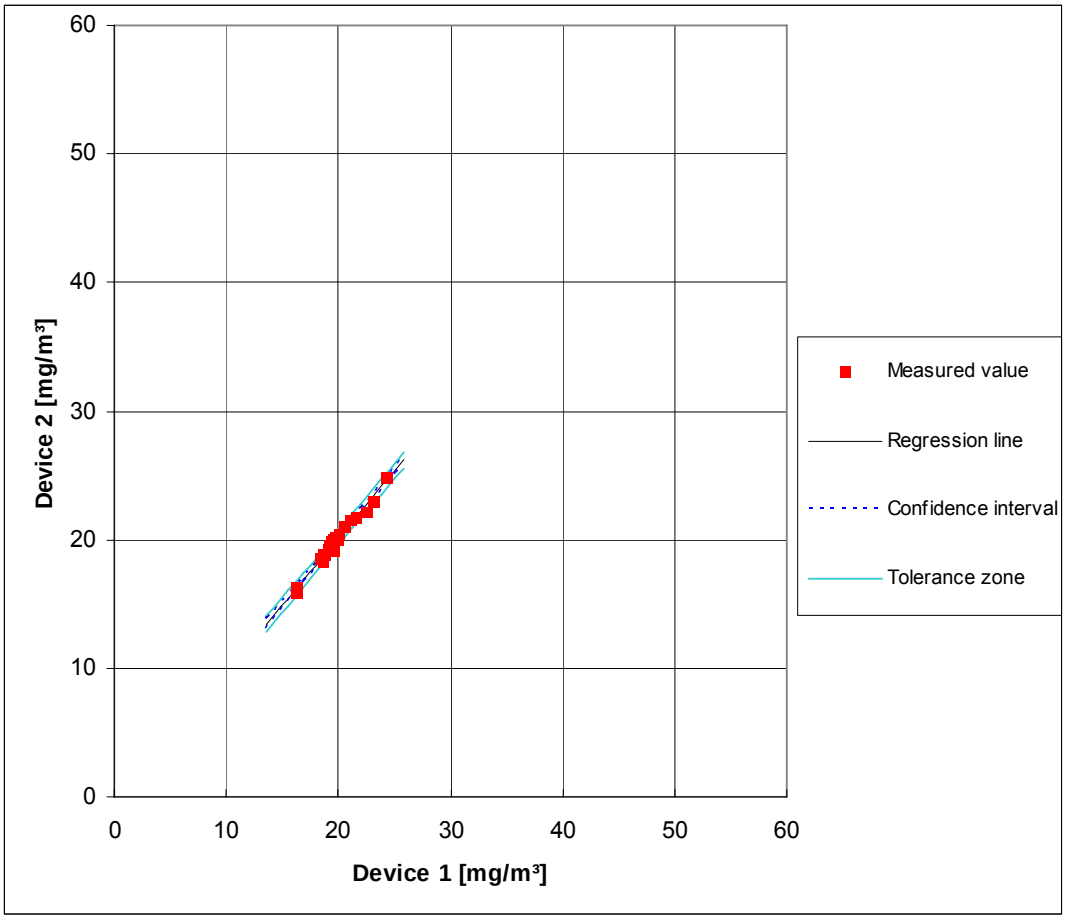


Figure 12: Graphics of the reproducibility R_D from the data near B_1 out of the field test

Table 28: Evaluation of the reproducibility R_D of all data in the field test

Reproducibility in the field test				
No. of values	n	=	2193	
Reference value		=	20	mg/m³
t-value for the selected safety	t95	=	1.961	
Standard deviation out of parallel measurements	sd	=	0.317	
Reproducibility R_D	**R(d)**	**=**	**32**	
Standard deviation	s	=	0.360	
Coefficient of correlation	r	=	0.9985	
Y = b* x + c Slope	b	=	1.024	
Intercept	c	=	0.131	mg/m³
Mean value	Unit 1	=	3.573	mg/m³
Mean value	Unit 2	=	3.791	mg/m³

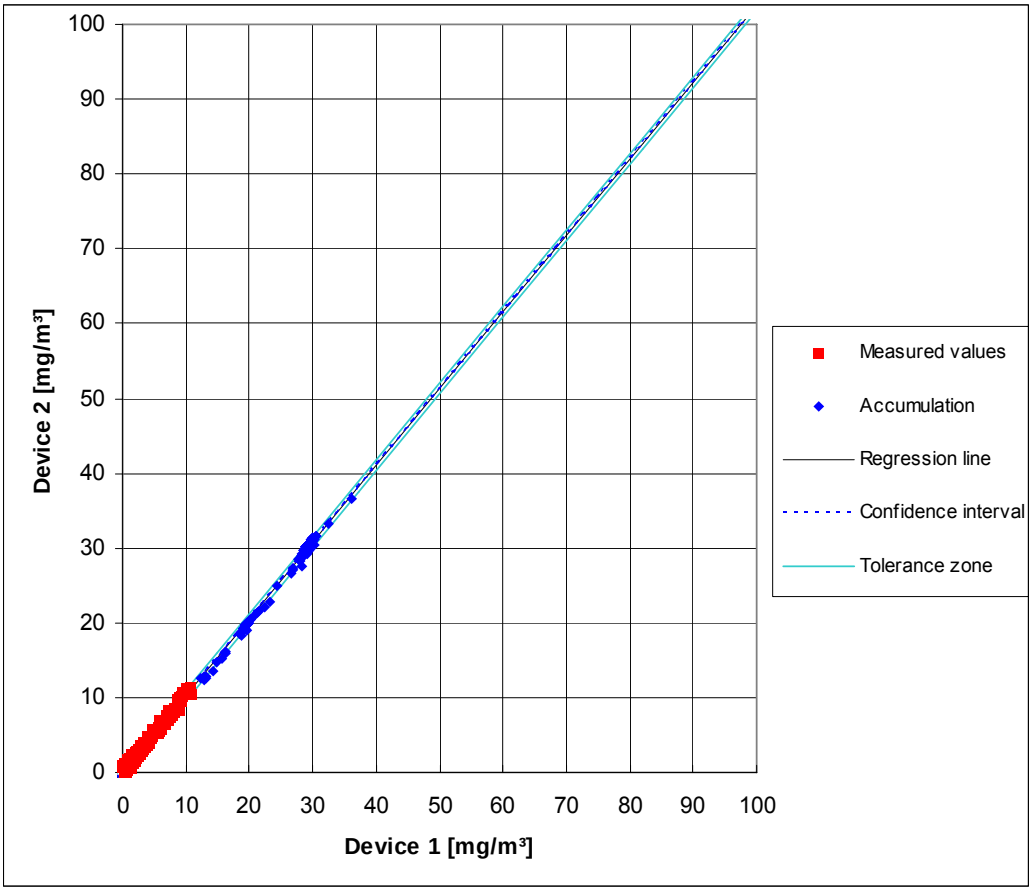


Figure 13: Graphics of the reproducibility R_D from all data out of the field

The minimum value of 10 stated in VDI 4202 part 1 is exceeded in both cases. For the calculation of total uncertainty regarding VDI 4202 the reproducibility at B_1 = 51 has been used.

The standard deviation under field conditions required in the EN 14626 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

Because of the very low CO-content in ambient air during the field test, the determination of the standard deviation according to EN 14626 during the field test with reference to the mean value of the field test is not reasonable. Therefore the 8h-limit value for CO of 10 mg/m³ was drawn on for the determination of the standard deviation. Hence there is a standard deviation of 3.18 %. 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 in this case the 8h-limit value for CO of 10 mg/m³. Thus the standard deviation is kept under field conditions.

6.5 Assessment

The minimum value of 10 for the reproducibility R_D 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 14626 is kept.

Minimum requirement fulfilled? yes

6.6 Documentation

Table 29: Single values of the laboratory test for the reproducibility R_D

Single values for the reproducibility		
No.	Unit 1	Unit 2
1	20.21	20.59
2	20.22	20.73
3	20.30	20.72
4	20.34	20.67
5	20.57	21.06
6	20.51	20.99
7	20.65	21.07
8	21.04	21.53
9	21.59	22.11
10	21.93	22.29
Average value	**20.73**	**21.17**

6.1 5.2.13 Hourly averages

The measurement method shall allow for formation of hourly averages.

EN 14626: 8.4.12 The averaging effect must be ≤ 7 % of the measured value.

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 14626 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 14626:

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

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

During the tests the following averages have been calculated:

Constant average [mg/m³]		Variable average [mg/m³]	
Unit 1	82.4	Unit 1	40.4
Unit 2	81.0	Unit 2	41.4

The calculated averaging effect from the values in Table 63 and Table 64 is

Unit 1: 1.94 %

Unit 2: -2.22 %.

6.5 Assessment

The measuring equipment allows the formation of one-hour mean values. During the examination of the averaging effect according to EN 14626 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 14626: 8.4.10 Sensitivity coefficient to electrical voltage ≤ 0.30 µmol/mol/V (corresponds to 0.3 ppm/V or 0.348 (mg/m³)/V)

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.

According to the test orders of the EN 14626 the sensitivity coefficient of the mains voltage should be determined with test gas concentrations around zero and at 70 - 80 % of the measuring range.

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

At the variation of the mains voltage analyser 1 shows the following results:

Table 30: Variation of mains voltage analyser 1

Unit No. 1 NP

			Deviation		Deviation
Measurement	**230 V**	**210 V**	**210 V to 230 V**	**245 V**	**245 V to 230 V**
	[mg/m³]	**[mg/m³]**	**[mg/m³]**	**[mg/m³]**	**[mg/m³]**
1	2.0	2.0	**0.0**	2.0	**0.0**
2	2.0	2.0	**0.0**	2.0	**0.0**
3	2.0	2.0	**0.0**	2.0	**0.0**
Average	2.0	2.0	**0.0**	2.0	**0.0**

Unit Nr. 1 RP

			Deviation		Deviation
Measurement	**230 V**	**210 V**	**210 V to 230 V**	**245 V**	**245 V to 230 V**
	[mg/m³]	**[mg/m³]**	**[mg/m³]**	**[mg/m³]**	**[mg/m³]**
1	53.7	53.6	**-0.1**	53.5	**-0.2**
2	53.7	53.7	**0.0**	53.7	**0.0**
3	53.6	53.6	**0.0**	53.6	**0.0**
Average	53.7	53.6	**0.0**	53.6	**-0.1**

At the variation of the mains voltage analyser 2 shows the following results:

Table 31: Variation of mains voltage analyser 2

Unit No. 2 NP

			Deviation		Deviation
Measurement	**230 V**	**210 V**	**210 V to 230 V**	**245 V**	**245 V to 230 V**
	[mg/m³]	**[mg/m³]**	**[mg/m³]**	**[mg/m³]**	**[mg/m³]**
1	1.6	1.5	**-0.1**	1.5	**-0.1**
2	1.6	1.6	**0.0**	1.6	**0.0**
3	1.5	1.6	**0.1**	1.5	**0.0**
Average	1.6	1.6	**0.0**	1.5	**0.0**

Unit No. 2 RP

			Deviation		Deviation
Measurement	**230 V**	**210 V**	**210 V to 230 V**	**245 V**	**245 V to 230 V**
	[mg/m³]	**[mg/m³]**	**[mg/m³]**	**[mg/m³]**	**[mg/m³]**
1	53.5	53.6	**0.1**	53.5	**0.0**
2	53.5	53.5	**0.0**	53.5	**0.0**
3	53.6	53.6	**0.0**	53.5	**-0.1**
Average	53.5	53.6	**0.0**	53.5	**0.0**

In comparison to the B_0 value of carbon monoxide which is 1 mg/m³ is, all deviations at the zero and span point during the variation of the mains voltage are in the required limits. The greatest deviation of both devices -0.1 mg/m³ for device 1 and 0.0 mg/m³ for device 2 have been taken for the calculation of total uncertainty of VDI 4202.

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 32 and Table 33:

Table 32: Variation of mains frequency analyser 1

Unit Nr. 1 NP

			Deviation		Deviation
Measurement	**50 Hz**	**48 Hz**	**48 Hz to 50 Hz**	**52 Hz**	**52 Hz to 50 Hz**
	[mg/m³]	**[mg/m³]**	**[mg/m³]**	**[mg/m³]**	**[mg/m³]**
1	1.9	2.0	**0.1**	2.0	**0.0**
2	2.0	2.0	**0.0**	2.0	**0.0**
3	2.0	2.0	**0.0**	2.0	**0.0**
Average	2.0	2.0	**0.0**	2.0	**0.0**

Unit Nr. 1 RP

			Deviation		Deviation
Measurement	**50 Hz**	**48 Hz**	**48 Hz to 50 Hz**	**52 Hz**	**52 Hz to 50 Hz**
	[mg/m³]	**[mg/m³]**	**[mg/m³]**	**[mg/m³]**	**[mg/m³]**
1	53.6	53.6	**0.0**	53.7	**0.1**
2	53.6	53.7	**0.1**	53.6	**0.0**
3	53.6	53.7	**0.1**	53.6	**0.0**
Average	53.6	53.7	**0.1**	53.6	**0.0**

Table 33: Variation of mains frequency analyser 2

Unit Nr. 2 NP

			Deviation		Deviation
Measurement	**50 Hz**	**48 Hz**	**48 Hz to 50 Hz**	**52 Hz**	**52 Hz to 50 Hz**
	[mg/m³]	**[mg/m³]**	**[mg/m³]**	**[mg/m³]**	**[mg/m³]**
1	1.60	1.60	**0.00**	1.60	**0.00**
2	1.50	1.60	**0.10**	1.60	**0.10**
3	1.60	1.50	**-0.10**	1.60	**0.00**
Average	1.6	1.6	**0.0**	1.6	**0.0**

Unit Nr. 2 RP

			Deviation		Deviation
Measurement	**50 Hz**	**48 Hz**	**48 Hz to 50 Hz**	**52 Hz**	**52 Hz to 50 Hz**
	[mg/m³]	**[mg/m³]**	**[mg/m³]**	**[mg/m³]**	**[mg/m³]**
1	53.4	53.5	**0.1**	53.4	**0.0**
2	53.5	53.6	**0.1**	53.5	**0.0**
3	53.5	53.6	**0.1**	53.6	**0.1**
Average	53.5	53.6	**0.1**	53.5	**0.0**

The deviations in the tested frequency interval should be smaller than B_0 (1 mg/m³). This requirement is fulfilled.

The sensitivity coefficient of the voltage influence according to EN 14626 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 sensitivity coefficient to electrical voltage is:

Unit 1: 0.0 (mg/m³)/V is 0.0 (nmol/mol/V)

Unit 2: 0.0 (mg/m³)/V is 0.0 (nmol/mol/V)

6.5 Assessment

The measuring system fulfils the minimum requirements regarding the variations of the mains voltage and the mains frequency. The minimum requirements are fallen below clearly. The sensitivity coefficient of the voltage according to EN 14626 is 0.0 (mg/m³)/V).

Minimum requirement fulfilled? yes

6.6 Documentation

See Table 30 to Table 33.

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 48i 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 14626: 8.5.7 Availability of the measuring system > 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:

Formel 1: Calculation of the availability

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

with:

- t_E Operating time
- t_K Calibration time
- t_A Outage time
- t_W Maintenance time
- V Availability

The periods of time for the determination of the availability for both analysers are to be seen in Table 34:

Table 34: Availability Thermo 48i

			Unit 1	Unit 2
Operating time	t_E	h	2193	2193
Calibration time	t_K	h	46	46
Outage time	t_A	h	0	0
Maintenance time	t_W	h	2	2
Availability	V	%	98 %	98 %

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 14626 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 34 the availability is calculated to 98 %.

6.5 Assessment

The availability is higher than 90 %, so that the minimum requirement is fulfilled. The performance criteria according to EN 14626 are fulfilled by an availability of 98 %.

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 %.

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.

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 14626: 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

A theoretical maintenance interval results from the average temporal change of the zero point for the two measuring systems.

Table 35: Maintenance interval at zero level from the drift tests

	Daily Drift [mg/(m³*d)]	Interval [Days] VDI 4202	Interval [Days] EN 14626
Unit 1	0.024	41	24
Unit 2	0.018	55	32

For the drift of the measured value and the resulted calibration work the following temporal periods have been found. The Intervals are calculated by a regression of the drift behaviour:

Table 36: Maintenance interval at span level from the drift tests

	Daily Drift [mg/(m³*d)]	Interval [Days] VDI 4202	Interval [Days] EN 14626
Unit 1	0.029	34	172
Unit 2	0.027	37	185

The number of the days results from the permissible drift in the maintenance interval of 1 mg/m³ (VDI 4202 Sheet 1), divided by the drift determined daily, respectively from the permissible drift in the maintenance interval of 0.58 mg/m³ (Zero) and 5 mg/m³ (Span) (EN 14626), divided by the drift determined daily.

Besides the drift additional maintenance operations influence the duration of the maintenance interval, which at the Thermo 48i 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 34 days according to VDI 4202 Sheet 1 and of at least 24 days according to the standard EN 14626.

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.

6.5 Assessment

According to the requirements of the VDI 4202 part 1, the measuring equipment can be awarded with the present results the maximum possible at a field testing-period of 3 months with a maintenance interval of 1 month.. On the basis of the requirements of the EN 14626 the determined maintenance interval is at least 24 days.

Minimum requirement fulfilled? yes

6.6 Documentation

Here not essential.

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 37: Expanded uncertainty for single values, device 1, reference value 20 mg/m³

Performance characteristic Device 1	**Requirement**	**Result**		**Uncertainty u**	**Squared uncertainty u²**
				µg/m³	(µg/m³)²
Reproducibility	10	51		0,20	0,04
Linearity	0,6 mg/m³	0,32	mg/m³	0,18	0,03
Temperature dependence at zero	1 mg/m³	-0,11	mg/m³	-0,06	0,00
Temperature dependence at span	1 mg/m³	0,73	mg/m³	0,42	0,18
Drift at zero	1 mg/m³	0,72	mg/m³	0,42	0,17
Drift at span	1 mg/m³	0,87	mg/m³	0,50	0,25
Mains voltage	1 mg/m³	0,27	mg/m³	0,16	0,02
Cross-sensitivities	1,8 mg/m³	-0,10	mg/m³	-0,06	0,00
Uncertainty of test gas	0,2 mg/m³	0,2	mg/m³	0,20	0,04
				Σu²	0,75
				U(c) = 2u(c)	1,73
				U(c) / Reference	**8,64**

Table 38: Expanded uncertainty for single values, device 2, reference value 20 mg/m³

Performance characteristic Device 2	**Requirement**	**Result**		**Uncertainty u**	**Squared uncertainty u²**
				µg/m³	(µg/m³)²
Reproducibility	10	51		0,20	0,04
Linearity	0,6 mg/m³	-0,16	mg/m³	-0,09	0,01
Temperature dependence at zero	1 mg/m³	0,09	mg/m³	0,05	0,00
Temperature dependence at span	1 mg/m³	0,28	mg/m³	0,16	0,03
Drift at zero	1 mg/m³	0,55	mg/m³	0,32	0,10
Drift at span	1 mg/m³	0,81	mg/m³	0,47	0,22
Mains voltage	1 mg/m³	-0,89	mg/m³	-0,51	0,26
Cross-sensitivities	1,8 mg/m³	0,00	mg/m³	0,00	0,00
Uncertainty of test gas	0,2 mg/m³	0,2	mg/m³	0,20	0,04
				Σu²	0,70
				U(c) = 2u(c)	1,67
				U(c) / Reference	**8,36**

Table 39: Expanded uncertainty for average values, device 1, reference value 20 mg/m³

Performance characteristic Device 1	**Uncertainty (Single value)**	**Time basis**	**Number nk**	**Squared uncertainty (average)**
				$(\mu g/m^3)^2$
Reproducibility	0.20	1 hour	7884	0.000
Linearity	0.18	1 year	1	0.034
Temperature dependence at zero	-0.06	1 year	1	0.004
Temperature dependence at span	0.42	1 year	1	0.178
Drift at zero	0.42	4 weeks	12	0.014
Drift at span	0.50	4 weeks	12	0.021
Mains voltage	0.16	1 year	1	0.024
Cross-sensitivities	-0.06	3 months	4	0.001
Uncertainty of test gas	0.20	1 year	1	0.040
			$\Sigma u_m^2(c_k)$	0.316
			$U(\bar{c}) = 2u(\bar{c})$	1.12
			$\frac{U(\bar{c})}{\text{Reference}}$	5.62

Table 40: Expanded uncertainty for average values, device 2, reference value 20 mg/m³

Performance characteristic Device 2	**Uncertainty (Single value)**	**Time basis**	**Number nk**	**Squared uncertainty (average)**
				$(\mu g/m^3)^2$
Reproducibility	0.20	1 hour	7884	0.000
Linearity	-0.09	1 year	1	0.009
Temperature dependence at zero	0.05	1 year	1	0.003
Temperature dependence at span	0.16	1 year	1	0.026
Drift at zero	0.32	4 weeks	12	0.008
Drift at span	0.47	4 weeks	12	0.018
Mains voltage	-0.51	1 year	1	0.264
Cross-sensitivities	0.00	3 months	4	0.000
Uncertainty of test gas	0.20	1 year	1	0.040
			$\Sigma u_m^2(c_k)$	0.368
			$U(\bar{c}) = 2u(\bar{c})$	1.21
			$\frac{U(\bar{c})}{\text{Reference}}$	6.07

The expanded uncertainty of measurement is to be compared with the required uncertainty of 15 % for the carbon monoxide component for continuous measurements. It is to be considered, that for the calculation of the expanded uncertainty instead of the IGW 2 value, which does not exist for CO, the reference value 1 has been used. For the calculation with the reference value 1 of 20 mg/m³ a maximum mistake of 8.64 % for single values and of 6.07 % for average values has been observed.

6.5 Assessment

The measuring system falls below the required expanded uncertainty of 15 % clearly by a result of maximum 8.64 % for single values and of maximum 6.07 % for average values.

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 14626

7.1 8.4.7 Sensitivity coefficient to sample gas pressure

The sensitivity coefficient to sample gas pressure must be smaller than ≤ *0.70 µmol/mol/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 kPa ± 0.2 kPa and 110 kPa ± 2 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:

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

where:

b_{gp} 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 sensitivity coefficient to sample gas pressure is:

Unit 1: 0.10 (mg/m³)/kPa corresponds to 0.09 (µmol/mol/kPa)
Unit 2: 0.10 (mg/m³)/kPa corresponds to 0.09 (µmol/mol/kPa)

The calculated values for both analysers are deeper than 0.7 ppm/kPa, so that the requirements according to EN 14626 are kept.

7.5 Assessment

The sensitivity coefficient to sample gas pressure keeps the requirements of the EN 14626.

Minimum requirement fulfilled? yes

7.6 Documentation

Table 41: Test results of the variation of the sample gas pressure for the component CO

Unit 1				
Sample gas pressure	1. Rep.	2. Rep.	3. Rep.	Average
[kPa]	[ppm]	[ppm]	[ppm]	[ppm]
ca. 80.0	60,9	60,8	60,7	60,8
99.8	61,7	61,6	61,8	61,7
ca.110.0	63,7	63,7	63,8	63,7
	Difference 80.0 kPa and 110.0 kPa:			2,9

Unit 2				
Sample gas pressure	1. Rep.	2. Rep.	3. Rep.	Average
[kPa]	[ppm]	[ppm]	[ppm]	[ppm]
ca. 80.0	60,2	60,1	60,2	60,2
99.8	60,9	60,8	60,9	60,9
ca. 110.0	63,4	63,3	63,3	63,3
	Difference 80.0 kPa and 110.0 kPa:			3,1

7.1 8.4.8 Sensitivity coefficient to sample gas temperature

The sensitivity coefficient to sample gas temperature should be smaller than ≤ *0.30 µmol/mol/K.*

7.2 Equipment

Climate chamber.

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 (mg/m³)/K corresponds 0.01 (µmol/mol/K)

Unit 2: 0.01 (mg/m³)/K corresponds 0.01 (µmol/mol/K)

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

Unit 1: 0.02 (mg/m³)/K corresponds 0.01 (µmol/mol/K)

Unit 2: 0.05 (mg/m³)/K corresponds 0.04 (µmol/mol/K)

The minimum requirement of the EN 14626 of b_{gt} ≤ *0,3 µmol/mol/K* is in the allowed limits.

7.5 Assessment

The minimum requirements are kept.

Minimum requirement fulfilled? yes

7.6 Documentation

Here not essential.

7.1 8.4.13 Difference sample/calibration port

EN 14626 ; 8.4.13 : Difference sample/calibration port ≤ 1,0 %

8.4. 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 uropeation port.

7.4 Evaluation

		Unit 1			Unit 2		
Measurement	Expected value	CO via sample port	CO via calibration port	Dsc	CO via sample port	CO via calibration port	Dsc
	[ppm]	[ppm]	[ppm]	[%]	[ppm]	[ppm]	[%]
1	64.7	64.8	64.9		65.0	65.1	
2	64.7	64.8	64.7		65.0	64.9	
3	64.7	64.9	64.9		65.1	65.1	
4	64.7	64.9	64.8		64.9	65.0	
5	64.7	64.9	64.7		65.0	65.0	
6	64.7	64.8	64.9		65.1	65.1	
	0	0	0		0	0	
	Average	**64.9**	**64.8**	**0.0**	**65.0**	**65.0**	**0.0**

8.4. 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.

7.1 Appendix G (normative) Type approval according to EN 14626

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

1) The value of each individual performance characteristic tested in the laboratory shall fulfil the criterion stated in table 1 (see 8.2 in EN 14626).

2) The expanded uncertainty calculated from the standard uncertainties due to the values of the specific performance characteristics obtained in the laboratory tests shall fulfil the criterion as stated in the council directive 2000/69/EG. This criterion is the maximum uncertainty of hourly values of continuous measurements at the 8 hour mean value. The relevant specific performance characteristics and the calculation procedure are given in annex G of the EN 14626.

3) The value of each of the individual performance characteristics tested in the field shall fulfil the criterion stated in table 1(see 8.2 of the EN 14626).

4) The expanded uncertainty calculated from the standard uncertainties due to the values of the specific performance characteristics obtained in the laboratory and field tests shall fulfil the criterion as stated in the council directive 2000/69/EG. This criterion is the maximum uncertainty of hourly values of continuous measurements at the 8 hour mean value. The relevant specific performance characteristics and the calculation procedure are given in annex G of the EN 14626.

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.

8.4.□ Evaluation

to 1) The value of each single tested performance characteristic in the lab fulfils the criterion of the EN 14626

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 14626.

To 4) The expanded uncertainty, calculated of the specific performance characteristics obtained in the laboratory and the field tests, fulfils the performance criterion.

8.4.□ Assessment

The minimum requirements are kept.

Minimum requirement fulfilled? Yes

8.4. Documentation

The results to the topics 1 and 3 are summarized in Table 42.

The results of topic 2 can be found in Table 43 and in Table 44.

The results of topic 4 can be found in Table 45 and in Table 46.

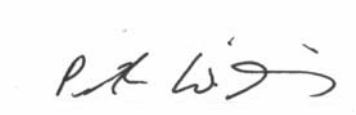
8 Recommendations for the use in practice

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/A1

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
- VDI 2459 Blatt 1: Messen gasförmiger Emissionen – Messen von Kohlenmonoxid-Konzentrationen mittels Flammionisationsdetektor nach Reduktion zu Methan, vom Dezember 2000. Berlin: Beuth Verlag
- VDI 2459 Blatt 7: Messen gasförmiger Emissionen – Messen von Kohlenmonoxid-Konzentrationen; Iodpentoxidverfahren, vom Februar 1994. Berlin: Beuth Verlag
- VDI 3490 Blatt 7: Messen von Gasen; Prüfgase; Dynamische Herstellung durch periodische Injektion, vom Dezember 1980. 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
- Directive 2000/69/EC of the □uropean parliament and of the council of 16 November 2000 relating to limit values for benzene and carbone monoxide in ambient
- EN 14626 Ambient air quality – Standard method for the measurement of the concentration of carbon monoxide by non dispersive infrared spectroscopy, from July 2005

10 Appendix

Appendix 1: Requirements according to EN 14626

Appendix 2: Measured and calculated values

Appendix 3: Manual

Appendix 1 : Requirements according to EN 14626

Table 42: Summary of the performance standards according to EN 14626

Performance characteristic	Criterion	Test result	ful-filled?	Page
8.4.5 Repeatability standard deviation at zero	≤ 1.0 µmol/mol	Device 1: 0.049 µmol/mol Device 2: 0.075 µmol/mol	yes	40
8.4.5 Repeatability standard deviation at concentration c_t	≤ 3.0 µmol/mol	Device 1: 0.075 µmol/mol Device 2: 0.080 µmol/mol	yes	40
8.4.6 Lack of fit (residual from the linear regression function)	Highest deviation from the linear regression function for concentrations higher than zero ≤ 4 % of the measured value Deviation at zero ≤ 0.2 µmol/mol	At zero point Device 1: 0.01 µmol/mol Device 2: -0.13 µmol/mol At span point Device 1: 0.28 µmol/mol corresponds to 0.81 % of nominal Device 2: -0.06 µmol/mol corresponds to -0.71 % of nominal	yes	36
8.4.7 Sensitivity coefficient of the sample gas pressure	≤ 0.7 µmol/mol/kPa	Device 1: 0.09 µmol/mol/kPa Device 2: 0.09 µmol/mol/kPa	yes	82
8.4.8 Sensitivity coefficient of the sample gas temperature	≤ 0.3 µmol/mol/K	Device 1: 0.01 µmol/mol/K Device 2: 0.04 µmol/mol/K	yes	84
8.4.9 Sensitivity coefficient of surrounding temperature	≤ 0.3 µmol/mol/K	At zero point Device 1: 0.01 µmol/mol/K Device 2: 0.005 µmol/mol/K At span point Device 1: 0.03 µmol/mol/K Device 2: 0.03 µmol/mol/K	yes	44 47
8.4.10 Sensitivity coefficient of electrical voltage	≤ 0.3 µmol/mol/V	Device 1: 0.0 µmol/mol/V Device 2: 0.0 µmol/mol/V	yes	66
8.4.11 Interferents at zero and at concentration ct (at a level of the 8-hour mean limit value)	$_{H2}H_2O$ ≤ 1.0 µmol/mol $_{CO2}$ ≤ 0.5 µmol/mol NO ≤ 0.5 µmol/mol $_{N2}N_2O$ ≤ 0.5 µmol/mol	Device 1: $_{H2}H_2O$ 0.17 µmol/mol at zero point -0.06 µmol/mol at span point $_{CO2}$ 0.0 µmol/mol at zero point 0.0 µmol/mol at span point NO 0.01 µmol/mol at zero point 0.09 µmol/mol at span point	yes	56

		$_{N2}N_2O$ 0.0 µmol/mol at zero point 0.0 µmol/mol at span point Device 2: $_{H2}H_2O$ -0.16 µmol/mol at zero point 0.0 µmol/mol at span point $_{CO2}$ 0.02 µmol/mol at zero point -0.11 µmol/mol at span point NO -0.01 µmol/mol at zero point -0.09 µmol/mol at span point $_{N2}N_2O$ 0.03 µmol/mol at zero point 0.11 µmol/mol at span point		
8.4.12 Averaging effect	≤ 7.0 % of the measured value	Device 1: 1.94 % Device 2: -2.22 %	yes	64
8.4.13 Difference sample/calibration port	≤ 1.0 %	Device 1: 0.0 % Device 2: 0.0 %	yes	86
8.4.3 Response time (rise)	≤ 180 s	Device 1: 50s Device 2: 50s	yes	42
8.4.3 Response time (fall)	≤ 180 s	Device 1: 55s Device 2: 55s	yes	42
8.4.3 Difference between rise time and fall time	≤ 10 % relative difference or 10 s. depending on which value is higher	Device 1: 11.7 %. absolute 6s Device 2: 12.3 % . absolute 6s	yes	42
8.5.6 Period of unattended operation	3 month or less if the manufacturer specifies a shorter period. but not less than 2 weeks	At least 24 days	yes	76
8.5.7 Availability of the analyser	> 90 %	98 %	yes	73
8.5.5 Reproducibility standard deviation under field conditions	≤ 5.0 % of the average over a period of 3 month	3.18 %	yes	59
8.5.4 Long-term drift at zero	≤ 0.5 µmol/mol	Device 1: 0.5 µmol/mol Device 2: 0.37 µmol/mol	yes	50
8.5.4 Long-term drift at span level	≤ 5.0 % of the maximum of the tested range	Device 1: 0.6 µmol/mol = 0.7 % Device 2: 0.56 µmol/mol = 0.65 %	yes	53
8.4.4 Short-term drift at zero	≤ 0.1 µmol/mol über 12 h	Device 1: 0.0 µmol/mol Device 2: 0.0 µmol/mol	yes	50
8.4.4 Short-term drift at span level	≤ 0.6 µmol/mol über 12 h	Device 1: 0.26 µmol/mol Device 2: -0.09 µmol/mol	yes	53

Table 43: Expanded uncertainty out of the results from the lab test EN 14626, device 1

Device:	Thermo Model 48i				Seriel No.	Device 1	
Measured component:	CO			8 hour mean limit value		8,62	µmol/mol

No.	Performance characteristic	Criterion	Result	Uncertainty		Square of uncertainty	
1	Repeatability standard deviation at zero	≤ 1,0 µmol/mol	0,049	$u_{r,z}$	0,01	0,0000	
2	Repeatability standard deviation at ct	≤ 3,0 µmol/mol	0,075	$u_{r,lv}$	0,00	0,0000	
3	"lack of fit" at the hourly alert threshold value	≤ 4,0% of measured value	0,810	$u_{l,lv}$	0,04	0,0016	
4	Variations in sample gas pressure	≤ 0,7 µmol/mol/kPa	0,090	u_{gp}	0,22	0,0502	
5	Variations in sample gas temperature	≤ 0,3 µmol/mol/K	0,010	u_{gt}	0,02	0,0005	
6	Variations in surrounding temperature	≤ 0,3 µmol/mol/K	0,030	u_{st}	0,07	0,0047	
7	Variations in electrical voltage	≤ 0,3 µmol/mol/V	0,000	u_{V}	0,00	0,0000	
8a	Interference H20 mit 21 mmol/mol	≤ 1,0 µmol/mol	0,138	u_{H2O}	0,09	0,0087	
8b	Interference CO2 mit 500 µmol/mol	≤ 0,5 µmol/mol	0,000	$u_{int,pos}$			
8c	Interference NO mit 1 µmol/mol	≤ 0,5 µmol/mol	0,026	oder	0,02	0,0002	
8d	Interference N2O mit 50 nmol/mol	≤ 0,5 µmol/mol	0,000	$u_{int,neg}$			
9	Averaging effect	≤ 7,0% of measured value	1,940	u_{av}	0,10	0,0093	
18	Difference sample/calibration port	≤ 1,0%	0,000	u_{Dsc}	0,00	0,0000	
23	Uncertainty test gas	≤ 3,0%	2,000	ucg	0,09	0,0074	

Combined standard uncertainty	u_c	0,2877	µmol/mol
Expanded uncertainty	U_c	0,5754	µmol/mol
Expanded uncertainty actual	$U_{c,rel}$	6,68	%
Expanded uncertainty required	$U_{req,rel.}$	15	%

Table 44: Expanded uncertainty out of the results from the lab test EN 14626, device 2

Device:	Thermo Model 48i				Seriel No.	Device 2	
Measured component:	CO			8 hour mean limit value		8,62	µmol/mol

No.	Performance characteristic	Criterion	Result	Uncertainty		Square of uncertainty	
1	Repeatability standard deviation at zero	≤ 1,0 µmol/mol	0,075	$u_{r,z}$	0,01	0,0001	
2	Repeatability standard deviation at ct	≤ 3,0 µmol/mol	0,080	$u_{r,lv}$	0,00	0,0000	
3	"lack of fit" at the hourly alert threshold value	≤ 4,0% of measured value	0,710	$u_{l,lv}$	0,04	0,0012	
4	Variations in sample gas pressure	≤ 0,7 µmol/mol/kPa	0,090	u_{gp}	0,22	0,0502	
5	Variations in sample gas temperature	≤ 0,3 µmol/mol/K	0,040	u_{gt}	0,09	0,0084	
6	Variations in surrounding temperature	≤ 0,3 µmol/mol/K	0,030	u_{st}	0,07	0,0047	
7	Variations in electrical voltage	≤ 0,3 µmol/mol/V	0,000	u_{V}	0,00	0,0000	
8a	Interference H20 mit 21 mmol/mol	≤ 1,0 µmol/mol	-0,143	u_{H2O}	0,10	0,0093	
8b	Interference CO2 mit 500 µmol/mol	≤ 0,5 µmol/mol	-0,007	$u_{int,pos}$			
8c	Interference NO mit 1 µmol/mol	≤ 0,5 µmol/mol	-0,026	OR	0,03	0,0007	
8d	Interference N2O mit 50 nmol/mol	≤ 0,5 µmol/mol	0,046	$u_{int,neg}$			
9	Averaging effect	≤ 7,0% of measured value	-2,220	u_{av}	-0,11	0,0122	
18	Difference sample/calibration port	≤ 1,0%	0,000	u_{Dsc}	0,00	0,0000	
23	Uncertainty test gas	≤ 3,0%	2,000	0	0,09	0,0074	

Combined standard uncertainty	u_c	0,3072	µmol/mol
Expanded uncertainty	U_c	0,6144	µmol/mol
Expanded uncertainty actual	$U_{c,rel}$	7,13	%
Expanded uncertainty required	$U_{req,rel.}$	15	%

Table 45: Expanded uncertainty out of the results from the lab and field test EN 14626, device 1

Device:	Thermo Model 48i					Seriel No.	Device 1	
Measured component:	CO					8 hour mean limit value	8,62	µmol/mol
No.	**Performance characteristic**	**Criterion**		**Result**	**Uncertainty**		**Square of uncertainty**	
1	Repeatability standard deviation at zero	≤	1,0 µmol/mol	0,049	$u_{r,Z}$	0,01	0,0000	
2	Repeatability standard deviation at ct	≤	3,0 µmol/mol	0,075	$u_{r,lv}$	not considered, as ur,lv = 0 < ur,f	-	
3	"lack of fit" at the hourly alert threshold value	≤	4,0% of measured value	0,810	$u_{l,lv}$	0,04	0,0016	
4	Variations in sample gas pressure	≤	0,7 µmol/mol/kPa	0,090	u_{gp}	0,22	0,0502	
5	Variations in sample gas temperature	≤	0,3 µmol/mol/K	0,010	u_{gt}	0,02	0,0005	
6	Variations in surrounding temperature	≤	0,3 µmol/mol/K	0,030	u_{st}	0,07	0,0047	
7	Variations in electrical voltage	≤	0,3 µmol/mol/V	0,000	u_V	0,00	0,0000	
8a	Interference H20 mit 21 mmol/mol	≤	1,0 µmol/mol	0,138	u_{H2O}	0,09	0,0087	
8b	Interference CO2 mit 500 µmol/mol	≤	0,5 µmol/mol	0,000	$u_{int,pos}$			
8c	Interference NO mit 1 µmol/mol	≤	0,5 µmol/mol	0,026	or	0,02	0,0002	
8d	Interference N2O mit 50 nmol/mol	≤	0,5 µmol/mol	0,000	$u_{int,neg}$			
9	Averaging effect	≤	7,0% of measured value	1,940	u_{av}	0,10	0,0093	
10	Reproducibility standard deviation in field	≤	5,0% of 3 month average	3,180	$u_{r,f}$	0,27	0,0751	
11	Long term drift at zero	≤	0,5 µmol/mol	0,500	$u_{d,l,z}$	0,29	0,0833	
12	Long term drift at span level	≤	5,0% of max of cert.range	0,700	$u_{d,l,lv}$	0,03	0,0012	
18	Difference sample/calibration port	≤	1,0%	0,000	u_{Dsc}	0,00	0,0000	
23	Uncertainty test gas	≤	3,0%	2,000	ucg	0,09	0,0074	
					Combined standard uncertainty	u_c	0,4924	µmol/mol
					Expanded uncertainty	U_c	0,9848	µmol/mol
					Expanded uncertainty actual	$U_{c,rel}$	11,42	%
					Expanded uncertainty required	$U_{req,rel.}$	15	%

Table 46: Expanded uncertainty out of the results from the lab and field test EN 14626, device 2

Device:	Thermo Model 48i					Seriel No.	Device 2	
Measured component:	CO					8 hour mean limit value	8,62	µmol/mol
No.	**Performance characteristic**	**Criterion**		**Result**	**Uncertainty**		**Square of uncertainty**	
1	Repeatability standard deviation at zero	≤	1,0 µmol/mol	0,075	$u_{r,Z}$	0,01	0,0001	
2	Repeatability standard deviation at ct	≤	3,0 µmol/mol	0,080	$u_{r,lv}$	not considered, as ur,lv = 0 < ur,f	-	
3	"lack of fit" at the hourly alert threshold value	≤	4,0% of measured value	0,710	$u_{l,lv}$	0,04	0,0012	
4	Variations in sample gas pressure	≤	0,7 µmol/mol/kPa	0,090	u_{gp}	0,22	0,0502	
5	Variations in sample gas temperature	≤	0,3 µmol/mol/K	0,040	u_{gt}	0,09	0,0084	
6	Variations in surrounding temperature	≤	0,3 µmol/mol/K	0,030	u_{st}	0,07	0,0047	
7	Variations in electrical voltage	≤	0,3 µmol/mol/V	0,000	u_V	0,00	0,0000	
8a	Interference H20 mit 21 mmol/mol	≤	1,0 µmol/mol	-0,143	u_{H2O}	0,10	0,0093	
8b	Interference CO2 mit 500 µmol/mol	≤	0,5 µmol/mol	-0,007	$u_{int,pos}$			
8c	Interference NO mit 1 µmol/mol	≤	0,5 µmol/mol	-0,026	oder	0,03	0,0007	
8d	Interference N2O mit 50 nmol/mol	≤	0,5 µmol/mol	0,046	$u_{int,neg}$			
9	Averaging effect	≤	7,0% of measured value	-2,220	u_{av}	-0,11	0,0122	
10	Reproducibility standard deviation in field	≤	5,0% of 3 month average	3,180	$u_{r,f}$	0,27	0,0751	
11	Long term drift at zero	≤	0,5 µmol/mol	0,370	$u_{d,l,z}$	0,21	0,0456	
12	Long term drift at span level	≤	5,0% of max of cert.range	0,650	$u_{d,l,lv}$	0,03	0,0010	
18	Difference sample/calibration port	≤	1,0%	0,000	u_{Dsc}	0,00	0,0000	
23	Uncertainty test gas	≤	3,0%	2,000	0	0,09	0,0074	
					Combined standard uncertainty	u_c	0,4650	µmol/mol
					Expanded uncertainty	U_c	0,9299	µmol/mol
					Expanded uncertainty actual	$U_{c,rel}$	10,79	%
					Expanded uncertainty required	$U_{req,rel.}$	15	%

Appendix 2 : Measured and calculated values

Table 47: Linearity Thermo 48i 1/5

Manufacturer	**Thermo**	Zero gas	**Synth. air**	Span gas	**CO 99.1 mg/m³**
Type	**48i**	Manufacturer	**Praxair**	Manufacturer	**Praxair**
Measuring range	**0 to 100 mg/m³**			Test	1 of 5
Component	**CO**				

No.	**Date**	**Values Expectancy [mg/m³]**	**Measured [mg/m³]**	**Regression**	
Unit 1		0	0.03		
		9.91	10.00		
		19.82	19.83		
		29.73	29.90		
		39.64	39.90		
		49.55	49.70		
		59.46	58.90		
		69.37	69.20		
		79.28	79.10	Slope	0.9982
		89.19	89.10	Intercept	0.0784
		99.1	99.30	Correlation coefficient	1
Unit 2		0	-0.22		
		9.91	9.85		
		19.82	19.70		
		29.73	29.50		
		39.64	39.70		
		49.55	49.70		
		59.46	59.30		
		69.37	69.80		
		79.28	79.20	Slope	1.0027
		89.19	89.30	Intercept	-0.1466
		99.1	99.10	Correlation coefficient	1

Table 48: Linearity Thermo 48i 2/5

Manufacturer	**Thermo**	Zero gas	**Synth. air**	Span gas	**CO 99.1 mg/m³**	
Type	**48i**	Manufacturer	**Praxair**	Manufacturer	**Praxair**	Manufacturer
Measuring range	**0 to 100 mg/m³**		**0 to 100 mg/m³**		Test	2 of 5
Component	**CO**					

No.	**Date**	**Values Expectancy [mg/m³]**	**Measured [mg/m³]**	**Regression**	**Values Expectancy [mg/m³]**
Unit 1		0	0.01		
		9.91	10.03		
		19.82	19.86		
		29.73	29.90		
		39.64	40.00		
		49.55	49.70		
		59.46	59.20		
		69.37	69.20		
		79.28	79.20	Slope	0.9977
		89.19	89.00	Intercept	0.1354
		99.1	99.20	Correlation coefficient	1
Unit 2		0	-0.238		
		9.91	9.76		
		19.82	19.95		
		29.73	29.8		
		39.64	39.5		
		49.55	49.2		
		59.46	59.7		
		69.37	69.1		
		79.28	79.4	Slope	1.0039
		89.19	89.5	Intercept	-0.1889
		99.1	99.4	Correlation coefficient	1

Table 49: Linearity Thermo 48i 3/5

Manufacturer	**Thermo**	Zero gas	**Synth. air**	Span gas	**CO 99.1 mg/m³**	
Type	**48i**	Manufacturer	**Praxair**	Manufacturer	**Praxair**	Manufacturer
Measuring range	**0 to 100 mg/m³**		**0 to 100 mg/m³**		Test	3 of 5
Component	**CO**					

No.	**Date**	**Values Expectancy [mg/m³]**	**Measured [mg/m³]**	**Regression**	**Values Expectancy [mg/m³]**
Unit 1		0	0.04		
		9.91	10.04		
		19.82	19.96		
		29.73	29.80		
		39.64	39.90		
		49.55	49.80		
		59.46	59.20		
		69.37	69.20		
		79.28	79.10	Slope	0.9973
		89.19	89.00	Intercept	0.15
		99.1	99.20	Correlation coefficient	1
Unit 2		0	-0.29		
		9.91	9.74		
		19.82	19.66		
		29.73	29.60		
		39.64	39.30		
		49.55	49.70		
		59.46	59.50		
		69.37	69.70		
		79.28	79.50	Slope	1.0059
		89.19	89.40	Intercept	-0.2862
		99.1	99.30	Correlation coefficient	1

Table 50: Linearity Thermo 48i 4/5

Manufacturer	**Thermo**	Zero gas	**Synth. air**	Span gas	**CO 99.1 mg/m³**	
Type	**48i**	Manufacturer	**Praxair**	Manufacturer	**Praxair**	Manufacturer
Measuring range	**0 to 100 mg/m³**		**0 to 100 mg/m³**		Test	4 of 5
Component	**CO**					

No.	**Date**	**Values Expectancy [mg/m³]**	**Measured [mg/m³]**	**Regression**	**Values Expectancy [mg/m³]**
Unit 1		0	-0.025		
		9.91	10.02		
		19.82	19.76		
		29.73	29.9		
		39.64	40		
		49.55	49.8		
		59.46	59.2		
		69.37	69.2		
		79.28	78.9	Slope	0.9977
		89.19	89.2	Intercept	0.1157
		99.1	99.1	Correlation coefficient	1
Unit 2		0	0.288		
		9.91	10.04		
		19.82	19.73		
		29.73	29.6		
		39.64	39.5		
		49.55	49.9		
		59.46	59.8		
		69.37	69.8		
		79.28	79.3	Slope	1.0018
		89.19	89.3	Intercept	0.0594
		99.1	99.4	Correlation coefficient	1

Table 51: Linearity Thermo 48i 5/5

Manufacturer	**Thermo**	Zero gas	**Synth. air**	Span gas	**CO 99.1 mg/m³**	
Type	**48i**	Manufacturer	**Praxair**	Manufacturer	**Praxair**	Manufacturer
Measuring range	**0 to 100 mg/m³**		**0 to 100 mg/m³**		Test	5 of 5
Component	**CO**					

No.	**Date**	**Values Expectancy [mg/m³]**	**Measured [mg/m³]**	**Regression**	**Values Expectancy [mg/m³]**
Unit 1		0	0.007		
		9.91	9.8		
		19.82	19.8		
		29.73	29.6		
		39.64	40		
		49.55	49.4		
		59.46	59.2		
		69.37	69.5		
		79.28	79.2	Slope	1.001
		89.19	89.3	Intercept	-0.0523
		99.1	99.2	Correlation coefficient	1
Unit 2		0	-0.296		
		9.91	9.82		
		19.82	19.71		
		29.73	29.6		
		39.64	39.4		
		49.55	49.3		
		59.46	59.6		
		69.37	69.1		
		79.28	79.6	Slope	1.0047
		89.19	89.4	Intercept	-0.2774
		99.1	99.3	Correlation coefficient	1

Table 52: Single values of the repeatability in the lab

Measurement No.	Unit 1		Unit 2	
	ZP	SP	ZP	SP
	[mg/m³]	[mg/m³]	[mg/m³]	[mg/m³]
1	0.02	48.30	0.14	47.40
2	0.25	48.40	0.06	47.70
3	0.27	48.30	0.09	47.60
4	0.27	48.40	0.10	47.70
5	0.27	48.40	0.08	47.60
6	0.26	48.40	0.12	47.60
7	0.28	48.50	0.12	47.60
8	0.28	48.50	0.13	47.50
9	0.29	48.50	0.14	47.60
10	0.28	48.50	0.11	47.60
11	0.27	48.50	0.14	47.50
12	0.29	48.40	0.17	47.60
13	0.26	48.50	0.10	47.70
14	0.28	48.50	0.13	47.70
15	0.29	48.60	0.14	47.80
16	0.28	48.50	0.12	47.60
17	0.27	48.40	0.13	47.50
18	0.28	48.40	0.15	47.60
19	0.26	48.60	0.16	47.70
20	0.27	48.60	0.18	47.70

Table 53: Single values of the repeatability in the field

Measurement No.	Unit 1		Unit 2	
	ZP	SP	ZP	SP
	[mg/m³]	[mg/m³]	[mg/m³]	[mg/m³]
1	0.10	53.80	0.14	53.80
2	0.09	53.70	0.06	53.90
3	0.14	53.60	0.09	53.80
4	0.13	53.80	0.10	53.80
5	0.13	53.90	0.08	53.70
6	0.10	53.80	0.12	53.80
7	0.15	53.80	0.12	53.70
8	0.16	53.70	0.13	53.80
9	0.16	53.90	0.14	53.90
10	0.16	53.80	0.11	53.90
11	0.16	53.90	0.14	54.00
12	0.17	53.80	0.17	53.80
13	0.16	53.60	0.10	53.60
14	0.16	53.70	0.13	53.90
15	0.17	53.60	0.14	53.80

Table 54: Single values and evaluation of the dependence of the zero value from ambient temperature according to VDI 4202 part 1

Temperature [°C]	**Unit 1**			**Unit 2**		
	Rep. 1	**Rep. 2**	**Rep. 3**	**Rep. 1**	**Rep. 2**	**Rep. 3**
20	0.10	0.09	0.08	0.13	0.16	0.10
	0.07	0.07	0.10	0.15	0.12	0.14
	0.13	0.10	0.12	0.10	0.13	0.15
Average	0.10	0.09	0.10	0.13	0.14	0.13
5	0.17	0.15	0.13	0.21	0.22	0.24
	0.14	0.16	0.15	0.22	0.23	0.21
	0.16	0.19	0.17	0.20	0.21	0.22
Average	0.16	0.17	0.15	0.21	0.22	0.22
Deviation to 20°C	0.06	0.08	0.05	0.08	0.09	0.09
20	0.13	0.09	0.12	0.16	0.13	0.15
	0.08	0.09	0.08	0.13	0.14	0.10
	0.10	0.10	0.13	0.15	0.10	0.13
Average	0.10	0.10	0.11	0.15	0.12	0.13
40	0.01	0.02	-0.05	0.09	0.10	0.03
	-0.03	0.01	-0.01	0.07	0.06	0.08
	-0.01	-0.02	-0.05	0.05	0.07	0.05
Average	-0.01	0.00	-0.03	0.07	0.08	0.05
Deviation to 20 °C	-0.12	-0.09	-0.14	-0.08	-0.05	-0.07
20	0.10	0.10	0.12	0.13	0.14	0.10
	0.08	0.13	0.10	0.12	0.14	0.13
	0.12	0.10	0.09	0.14	0.15	0.16
Average	0.10	0.11	0.10	0.13	0.14	0.13
0	0.19	0.20	0.21	0.26	0.23	0.22
	0.20	0.21	0.22	0.22	0.21	0.24
	0.17	0.17	0.19	0.22	0.23	0.20
Average	0.19	0.19	0.20	0.23	0.22	0.22
Deviation to 20 °C	0.10	0.07	0.10	0.12	0.09	0.09

Table 55: Single values and evaluation of the dependence of the measured value from ambient temperature according to VDI 4202 part 1

Temperature [°C]	Unit 1 Rep. 1	Rep. 2	Rep. 3	Unit 2 Rep. 1	Rep. 2	Rep. 3
20	21.30	21.20	21.30	21.10	21.30	21.30
	21.50	21.30	21.10	21.20	21.30	21.10
	21.20	21.10	21.20	21.20	21.20	21.20
Average	**21.33**	**21.20**	**21.20**	**21.17**	**21.27**	**21.20**
5	20.90	21.00	20.90	21.50	21.40	21.50
	21.00	20.90	21.00	21.40	21.60	21.50
	21.00	21.00	21.00	21.40	21.50	21.60
Average	**20.97**	**20.97**	**20.97**	**21.43**	**21.50**	**21.53**
Deviation to 20°C	**-0.37**	**-0.23**	**-0.23**	**0.27**	**0.23**	**0.33**
20	21.30	21.30	21.20	21.30	21.10	21.20
	21.20	21.20	21.30	21.20	21.20	21.30
	21.10	21.20	21.20	21.20	21.10	21.20
Average	**21.20**	**21.23**	**21.23**	**21.23**	**21.13**	**21.23**
40	21.10	20.90	21.20	20.90	21.00	20.90
	21.00	21.00	21.00	20.90	20.90	20.90
	21.00	21.10	21.10	21.10	21.00	21.00
Average	**21.03**	**21.00**	**21.10**	**20.97**	**20.97**	**20.93**
Deviation to 20 °C	**-0.17**	**-0.23**	**-0.13**	**-0.27**	**-0.17**	**-0.30**
20	21.20	21.10	21.20	21.20	21.20	21.20
	21.30	21.20	21.20	21.10	21.10	21.10
	21.20	21.30	21.30	21.10	21.10	21.20
Average	**21.23**	**21.20**	**21.23**	**21.13**	**21.13**	**21.17**

Table 56: Single values and evaluation of the dependence of the measured value from ambient temperature according to EN 14626

Temperature [°C]	**Unit 1**			**Unit 2**		
	Rep. 1	**Rep. 2**	**Rep. 3**	**Rep. 1**	**Rep. 2**	**Rep. 3**
20	75.66	75.66	75.66	75.40	75.53	75.40
	75.79	75.92	75.79	75.66	75.79	75.53
	75.66	75.53	75.66	75.66	75.66	75.79
Average	**75.70**	**75.70**	**75.70**	**75.57**	**75.66**	**75.57**
0	75.14	74.88	74.75	76.18	76.18	76.31
	74.75	74.88	74.88	76.31	76.05	76.31
	74.75	75.01	74.88	76.18	76.44	76.18
Average	**74.88**	**74.92**	**74.84**	**76.22**	**76.22**	**76.27**
Deviation to 20°C	**-0.82**	**-0.78**	**-0.87**	**0.65**	**0.56**	**0.69**
20	75.92	75.79	75.79	75.92	75.66	75.66
	75.53	75.66	75.79	75.66	75.53	75.66
	75.53	75.66	75.53	75.53	75.40	75.40
Average	**75.66**	**75.70**	**75.70**	**75.70**	**75.53**	**75.57**
30	75.27	75.27	75.27	74.88	75.01	75.01
	75.27	75.27	75.40	74.75	74.75	74.75
	75.40	75.53	75.27	75.01	74.88	74.75
Average	**75.31**	**75.36**	**75.31**	**74.88**	**74.88**	**74.84**
Deviation to 20 °C	**-0.35**	**-0.35**	**-0.39**	**-0.82**	**-0.65**	**-0.74**
20	75.66	75.79	75.66	75.40	75.40	75.79
	75.92	75.79	75.79	75.79	75.66	75.40
	75.79	75.66	75.92	75.66	75.66	75.66
Average	**75.79**	**75.75**	**75.79**	**75.62**	**75.57**	**75.62**

Table 57: Evaluation of the short term drift according to EN 14626. Unit 1

Start values			Values after 12 h	
ZP [mg/m³]	SP [mg/m³]		ZP [mg/m³]	SP [mg/m³]
0.1	67.5		0.1	67.8
0.1	67.6		0.1	67.8
0.1	67.6		0.1	67.8
0.1	67.6		0.1	67.8
0.0	67.6		0.1	67.9
0.1	67.7		0.1	67.9
0.0	67.6		0.1	67.9
0.1	67.6		0.1	67.9
0.1	67.6		0.1	67.8
0.1	67.6		0.1	67.8
0.1	67.6		0.1	67.8
0.1	67.6		0.1	67.8
0.1	67.6		0.1	67.9
0.1	67.6		0.1	67.9
0.1	67.6		0.1	67.8
0.1	67.6		0.1	67.8
0.1	67.6		0.1	68.1
0.1	67.6		0.1	67.8
0.1	67.6		0.1	67.8
0.1	67.6		0.1	67.9
0.1	**67.6**		**0.1**	**67.9**

Table 58: Evaluation of the short term drift according to EN 14626. Unit 2

Start values			Values after 12 h	
ZP [mg/m³]	SP [mg/m³]		ZP [mg/m³]	SP [mg/m³]
0.1	67.5		0.1	67.5
0.1	67.5		0.1	67.5
0.1	67.6		0.1	67.5
0.1	67.7		0.1	67.5
0.1	67.6		0.1	67.4
0.1	67.6		0.1	67.4
0.1	67.6		0.1	67.4
0.2	67.6		0.2	67.5
0.1	67.6		0.2	67.5
0.1	67.6		0.2	67.5
0.1	67.6		0.1	67.5
0.1	67.6		0.1	67.5
0.1	67.6		0.1	67.5
0.2	67.6		0.1	67.4
0.1	67.7		0.1	67.4
0.1	67.7		0.1	67.4
0.1	67.6		0.1	67.5
0.1	67.6		0.1	67.6
0.1	67.6		0.1	67.5
0.1	67.6		0.2	67.5
0.1	**67.6**		**0.1**	**67.5**

Table 59: Cross-sensitivities at the zero point unit 1

Interferents		1. Rev.	2. Rev.	3. Rev.	Average	Deviation
	mg/m³	ZP	ZP	ZP	ZP	ZP
CO_2	SL	0.268	0.265	0.246	0.26	
	700	0.273	0.261	0.253	0.26	0.00
NO2	SL	0.281	0.285	0.274	0.28	
	60	0.282	0.277	0.29	0.28	0.00
H2O	SL	0.054	0.009	-0.002	0.02	
	ca. 80 % rel.	0.235	0.219	0.195	0.22	0.20
SO2	SL	0.277	0.273	0.259	0.27	
	0.7	0.271	0.264	0.265	0.27	0.00
NO	SL	0.26	0.293	0.27	0.27	
	1	0.283	0.284	0.279	0.28	0.01
Ozone	SL	0.015	0.041	0.136	0.06	
	0.36	0.04	0.053	0.129	0.07	0.01
N2O	SL	0.237	0.269	0.265	0.26	
	0.5	0.251	0.273	0.26	0.26	0.00
H2S	SL	0.264	0.273	0.3	0.28	
	0.03	0.271	0.261	0.309	0.28	0.00
NH3	SL	0.191	0.23	0.238	0.22	
	0.03	0.24	0.249	0.25	0.25	0.03
Benzene	SL	0.348	0.354	0.343	0.35	
	1	0.34	0.35	0.346	0.35	0.00
		Sum of negative deviations				0.00
		Sum of positive deviations				0.24

Table 60: Cross-sensitivities at the zero point unit 2

Interferents		1. Rev.	2. Rev.	3. Rev.	Average	Deviation
	mg/m³	ZP	ZP	ZP	ZP	ZP
CO2	SL	-0.131	-0.132	-0.158	-0.14	
	700	-0.128	-0.105	-0.141	-0.12	0.02
NO2	SL	-0.124	-0.141	-0.144	-0.14	
	60	-0.128	-0.122	-0.171	-0.14	0.00
H2O	SL	0.116	-0.334	-0.275	-0.16	
	ca. 80 % rel.	0.778	-0.974	-0.838	-0.34	-0.18
SO2	SL	-0.178	-0.21	-0.189	-0.19	
	0.7	0.184	-0.198	-0.195	-0.07	0.12
NO	SL	-0.1	-0.139	-0.133	-0.12	
	1	-0.128	-0.119	-0.154	-0.13	-0.01
Ozone	SL	0.234	0.216	-0.192	0.09	
	0.36	0.273	0.189	-0.188	0.09	0.01
N2O	SL	0.136	-0.091	-0.083	-0.01	
	0.5	0.06	0.1	-0.122	0.01	0.03
H2S	SL	-0.162	-0.167	-0.191	-0.17	
	0.03	-0.183	-0.187	-0.213	-0.19	-0.02
NH3	SL	0.157	-0.013	-0.046	0.03	
	0.03	0.04	-0.042	-0.079	-0.03	-0.06
Benzene	SL	-0.044	-0.092	-0.101	-0.08	
	1	-0.049	-0.101	-0.104	-0.08	-0.01
		Sum of negative deviations				-0.28
		Sum of positive deviations				0.17

Table 61: Cross-sensitivities at the span point unit 1

Interferents		1. Rev.	2. Rev.	3. Rev.	Average	Deviation
	mg/m³	SP	SP	SP	SP	SP
CO2	SL	48.4	48.4	48.5	48.43	
	700	48.5	48.4	48.4	48.43	0.00
NO2	SL	48.4	48.5	48.5	48.47	
	60	48.5	48.5	48.6	48.53	0.07
H2O	SL	99.4	99.1	99.2	99.23	
	ca. 80 % rel.	99	99	99.5	99.17	-0.07
SO2	SL	48.5	48.5	48.4	48.47	
	0.7	48.4	48.5	48.5	48.47	0.00
NO	SL	48.4	48.5	48.4	48.43	
	1	48.5	48.5	48.6	48.53	0.10
Ozone	SL	48	48	48.1	48.03	
	0.36	48	48.1	48	48.03	0.00
N2O	SL	48.5	48.5	48.5	48.50	
	0.5	48.5	48.5	48.5	48.50	0.00
H2S	SL	48.6	48.5	48.6	48.57	
	0.03	48.5	48.6	48.6	48.57	0.00
NH3	SL	48.3	48.3	48.4	48.33	
	0.03	48.4	48.4	48.4	48.40	0.07
Benzene	SL	48.5	48.6	48.6	48.57	
	1	48.6	48.6	48.6	48.60	0.03
		Sum of negative deviations				-0.07
		Sum of positive deviations				0.27

Table 62: Cross-sensitivities at the span point unit 2

Interferents		1. Rev.	2. Rev.	3. Rev.	Average	Deviation
	mg/m³	SP	SP	SP	SP	SP
CO2	SL	48.3	48.1	47.7	48.03	
	700	48	47.8	47.9	47.90	-0.13
NO2	SL	48.6	47.8	47.8	48.07	
	60	48	47.7	47.6	47.77	-0.30
H2O	SL	99.6	99.8	99.7	99.70	
	ca. 80 % rel.	99.7	99.8	99.6	99.70	0.00
SO2	SL	47.3	47.5	47.5	47.43	
	0.7	47.5	47.5	47.6	47.53	0.10
NO	SL	48.1	47.9	47.6	47.87	
	1	47.9	47.7	47.7	47.77	-0.10
Ozone	SL	48.3	47.9	47.8	48.00	
	0.36	48.1	47.9	47.6	47.87	-0.13
N2O	SL	47.6	47.3	47.4	47.43	
	0.5	47.5	47.6	47.6	47.57	0.13
H2S	SL	47.6	47.6	47.5	47.57	
	0.03	47.5	47.5	47.5	47.50	-0.07
NH3	SL	48.1	47.9	47.6	47.87	
	0.03	47.9	47.7	47.6	47.73	-0.13
Benzene	SL	48	47.9	47.8	47.90	
	1	48	47.9	47.7	47.87	-0.03
		Sum of negative deviations				-0.90
		Sum of positive deviations				0.23

Table 63: Single values of the averaging-test according to EN 14626 Unit 1

Constant concentration		Variable concentration	
Time [min]	Measured value [mg/m³]	Time [min]	Measured value [mg/m³]
00:45	82.2	00:45	55.0
01:30	82.2	01:30	34.0
02:15	82.2	02:15	49.3
03:00	82.5	03:00	26.7
03:45	82.4	03:45	50.6
04:30	82.3	04:30	30.1
05:15	82.3	05:15	51.2
06:00	82.4	06:00	30.1
06:45	82.5	06:45	51.2
07:30	82.5	07:30	29.8
08:15	82.5	08:15	49.1
09:00	82.5	09:00	29.8
09:45	82.5	09:45	50.9
10:30	82.4	10:30	29.6
11:15	82.4	11:15	49.0
12:00	82.4	12:00	29.2
12:45	82.4	12:45	49.8
13:30	82.4	13:30	29.7
14:15	82.4	14:15	51.6
15:00	82.3	15:00	30.9
Average	**82.4**	**Average**	**40.4**

Table 64: Single values of the averaging-test according to EN 14626 Unit 2

Constant concentration		Variable concentration	
Time [min]	Measured value [mg/m³]	Time [min]	Measured value [mg/m³]
00:45	80.9	00:45	56.4
01:30	80.9	01:30	34.8
02:15	80.8	02:15	50.6
03:00	80.9	03:00	27.3
03:45	80.9	03:45	51.8
04:30	80.9	04:30	30.8
05:15	80.9	05:15	52.5
06:00	80.9	06:00	30.8
06:45	81.0	06:45	52.5
07:30	81.0	07:30	30.6
08:15	81.0	08:15	50.3
09:00	81.0	09:00	30.5
09:45	81.0	09:45	52.1
10:30	81.0	10:30	30.4
11:15	81.0	11:15	50.2
12:00	80.9	12:00	30.0
12:45	80.9	12:45	51.1
13:30	80.9	13:30	30.5
14:15	81.0	14:15	52.9
15:00	80.9	15:00	31.7
Average	**81.0**	**Average**	**41.4**

Figure 14: Reading of the software version at the analyser display

Appendix 3 : Manual