

Ethylene oxide – Method for the determination of ethylene oxide in workplace air using gas chromatography after solvent desorption

Air Monitoring Method

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Keywords

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Abstract

This analytical method is a validated measurement procedure for the determination of ethylene oxide [75-21-8] in workplace air averaged over the sampling period after personal or stationary sampling. Sampling is performed by drawing air through a tube filled with activated charcoal. The flow is set to 25 ml/min with a recommended air sample volume of 6 l. Sampling is performed over 40 min. The adsorbed ethylene oxide is desorbed using a toluene/carbon disulphide mixture (90+10 v/v) and converted to 2-bromoethanol using hydrobromic acid after the phases have separated and been filtered. The sample is analysed by means of gas chromatography (GC) with a mass selective detector (MSD). The quantitative evaluation is based on a calibration function obtained by means of a multiple-point calibration. The relative limit of quantification (LOQ) is 7 µg/m³ ethylene oxide for an air sample volume of 6 l. The mean recovery was 94% and the expanded uncertainties were between 20 and 21%.

This analytical method has been accredited by the accident insurance companies for the detection in workplace air of substances that are carcinogenic, mutagenic or toxic to reproduction.

This method has been tested and recommended for the determination of ethylene oxide at workplaces by the accident insurance companies.

Both personal and stationary sampling can be performed for measurements in order to evaluate work areas.

Name	Synonym	CAS No.	Molecular structure	Molar mass
Ethylene oxide	Oxirane	75-21-8	C ₂ H ₄ O	44.05

1 Summary

The mean concentration of ethylene oxide at the workplace over the sampling period can be determined with this method using personal or stationary sampling.

Measurement Principle:	A pump draws a defined volume of air through a tube filled with activated charcoal. The adsorbed ethylene oxide is desorbed using a toluene/carbon disulphide mixture (90+10 v/v) and converted to 2-bromoethanol using hydrobromic acid after the phases have separated and been filtered. For analytical determination a gas chromatograph with a mass-selective detector (MSD) is used.
Limit of quantification:	Absolute: 0.044 µg of ethylene oxide per adsorption tube Relative: 0.007 mg/m ³ of ethylene oxide for an air sample volume of 6 l, 3 ml of desorption solution and an injection volume of 2 µl
Measurement range:	Validated in the range of 0.018 mg/m ³ to 0.366 mg/m ³ at an air sample volume of 6 l.
Selectivity:	Interference by other components is eliminated by derivatisation and gas chromatographic separation combined with mass-selective detection.
Advantages:	Personal and selective measurements are possible.
Disadvantages:	No indication of concentration peaks.
Apparatus:	Pump Flow meter Activated charcoal tubes Gas chromatograph with MSD

2 Equipment and chemicals

2.1 Equipment

For sampling:

- Sampling pump, suitable for a flow rate of 25 ml/min, e.g. LFS 113, from Sensidyne, supplied by DEHA Haan & Wittmer, 71296 Heimsheim, Germany
- Flow meter, e.g. Gilibrator-2, from Sensidyne, St. Petersburg, FL 33716, USA
- Adsorption tubes packed with activated charcoal (standardised, comprising two separate fillings of activated charcoal, 600 mg and 300 mg), e.g. G type from MSA/Auer, supplied by Analyt, 79379 Müllheim, Germany

For the analysis:

- Volumetric flasks, 250 ml, 100 ml, 10 ml
- Microlitre syringes 1, 10, 25, 100 µl, e.g. from Hamilton, 7402 Bonaduz, Switzerland
- Airtight headspace syringe, 2.5 ml, e.g. from Gerstel, 45473 Mühlheim, Germany
- Variable piston pipette, e.g. Multipette Pro, from Eppendorf, 22339 Hamburg, Germany
- Syringe filter, e.g. Millipore Millex-FG PTFE 0.2 µm, from Merck, 64293 Darmstadt, Germany
- HP6890 gas chromatograph with mass-selective detector (MSD), from Agilent, 76447 Waldbronn, Germany
- MPS2 autosampler, from Gerstel

For the validation:

- N10 glass vials, 10 ml
- Withdrawal station with needle valve and septum access to withdraw gas from a gas cylinder

2.2 Chemicals

- Ethylene oxide, purity 99.3%, e.g. from Merck
- Carbon disulphide, p.a., e.g. from Baker, Avantor Performance Chemicals, Center Valley PA 18034, USA
- Toluene, purity 99.8%, e.g. from LGC Standards, 46485 Wesel, Germany
- Hydrobromic acid, purity 47%, e.g. from Merck
- Potassium carbonate, p. a., e.g. from Merck
- 1-Bromo-3-chloropropane (internal standard), purity 99%, e.g. from Merck
- 2-Bromoethanol, purity 98.2%, e.g. from Merck
- Gas to operate the gas chromatograph: Helium, purity 99.996%

2.3 Solutions

Stock solution internal standard: Solution of approx. 5.06 g of 1-bromo-3-chloropropane per l of toluene
32 µl of 1-bromo-3-chloropropane (density 1.596 g/cm³) are pipetted into a 10 ml volumetric flask, into which several millilitres of toluene have been previously placed, weighed exactly to the nearest 0.1 mg, filled to the mark with toluene and shaken.

Desorption agent: Toluene/carbon disulphide (90+10 v/v)
25 ml of carbon disulphide are placed in a 250 ml volumetric flask and the flask is then filled to the mark with toluene.

Desorption solution: Solution of approx. 1.01 µg of 1-bromo-3-chloropropane per ml of toluene/carbon disulphide mixture (90+10 v/v)
A pipette is used to add 50 µl of the stock solution of the internal standard to a 250 ml volumetric flask into which several millilitres of the desorption agent have been previously placed, it is filled to the mark with the desorption agent and shaken.

- Calibration stock solution 1:** Solution of approx. 5.71 mg of 2-bromoethanol per ml of desorption solution
33 µl of 2-bromoethanol (density 1.763 g/cm³) are pipetted into a 10 ml volumetric flask, into which several millilitres of desorption solution have been previously placed, it is weighed exactly to the nearest 0.1 mg, filled to the mark with desorption solution and shaken.
- Calibration stock solution 2:** Solution of approx. 57.1 µg of 2-bromoethanol per ml of desorption solution
0.1 ml of calibration stock solution 1 is pipetted into a 10 ml volumetric flask, into which several millilitres of desorption solution have been previously placed, and it is filled to the mark with desorption solution.
- Calibration solutions:** Solutions of approx. 0.14 µg to approx. 2.86 µg of 2-bromoethanol per ml of desorption solution
25, 100, 200, 300, 400 and 500 µl of calibration stock solution 2 are separately pipetted into six 10 ml volumetric flasks, into which several millilitres of desorption solution have been previously placed, and it is filled to the mark with desorption solution.
The concentrations of 2-bromoethanol in the calibration solutions are shown in Table 1. After conversion, the air concentrations of ethylene oxide, equivalent to an air sample volume of 6 l, are in the range of 0.02 mg/m³ up to 0.5 mg/m³.
The factor for converting the mass of 2-bromoethanol to ethylene oxide is 0.352.

Tab.1 Concentrations of 2-bromoethanol in the calibration solutions

Calibration solution	1	2	3	4	5	6
Addition [µl]	25	100	200	300	400	500
Concentration in the calibration solution [mg/l]	0.143	0.571	1.143	1.714	2.285	2.857
Concentration in air [mg/m ³] ^{a)}	0.025	0.101	0.201	0.302	0.403	0.503

^{a)} based on ethylene oxide, a desorption volume of 3 ml and an air sample volume of 6 l

3 Sampling

The tube filled with activated charcoal is connected to the pump and the flow rate is adjusted to 25 ml/min. The pump and tube are worn by a person during working hours or stationary sampling is carried out. A sampling period of four hours at the stated flow rate is possible with this method. After sampling, the adsorption tubes are sealed with the plastic caps.

Before and after sampling, the flow rate must be tested for constancy using a comparable sample carrier. If the deviation from the adjusted flow rate is greater than 5%, it is advisable to discard the sample (see DGUV Information 213-500 “General Part”, Section 3 (DGUV 2015)).

4 Analytical determination

4.1 Sample preparation and analysis

The contents of the loaded tube containing activated charcoal are transferred into a sample vial. After addition of 3 ml of desorption solution, the vessel is immediately sealed and treated for five minutes in the ultrasonic bath. The liquid phase is then transferred into another sample vial through a syringe filter, 25 µl of hydrobromic acid are added and the vial is shaken for 5 minutes on a shaker. Then approx. 100 mg of potassium carbonate (two small pinches) are used to neutralise the excess hydrobromic acid. The supernatant solution is transferred into an autosampler vial. The bromoethanol formed by the reaction of ethylene oxide with hydrobromic acid is then determined by means of gas chromatography.

The derivatisation must not be carried out in the presence of the activated charcoal.

In order to ensure that the desorption solution and the activated charcoal used do not contain any interfering impurities, the contents of an activated charcoal tube that has not been used for sampling are treated at regular intervals as described above (blank solution).

4.2 Operating conditions for chromatography

The characteristics of the method stated in [Section 5](#) were obtained under the following operating conditions:

Apparatus:	HP6890 gas chromatograph with mass-selective detector (MSD), from Agilent, and MPS2 autosampler, from Gerstel	
Separation column:	Rtx-Wax from Restek, inner diameter 0.25 mm, length 30 m, film thickness 0.5 µm	
Temperatures	Injector: 250 °C Column with temperature program: Initial temperature 75 °C, isothermal for 0.5 min Heating rate 25 °C/min up to 220 °C, isothermal for 2 min	
Injection volume:	2 µl	
Split:	Split ratio 2.5 : 1	
MSD parameters:	Ionisation type:	Electron impact ionisation (70 eV)
	Measurement mode:	SIM
	Dwell time:	25 msec
	Recorded masses (m/z)	<u>Quantification</u> / qualification
	2-Bromoethanol	45, <u>95</u> , 124 amu
	1-Bromo-2-chloropropane	41, <u>77</u> , 156, 158 amu
Gases:	Helium, 40 cm/s, constant flow rate 1.6 ml/min	

5 Evaluation

5.1 Calibration

The calibration solutions described in [Section 2.3](#) are analysed as described in [Section 4.1](#). The calibration curve is obtained by plotting the resulting peak area ratios of the relevant mass fractions of 2-bromoethanol and 1-bromo-2-chloropropane as an internal standard versus the concentration ratios of 2-bromoethanol and 1-bromo-2-chloropropane in the relevant calibration solutions.

5.2 Calculation of the analytical result

Based on the determined peak areas, the corresponding mass m in μg per sample is obtained from the calibration curve. The corresponding mass concentration (c) is calculated according to the following Equation (1):

$$c = \frac{m \times f}{V \times \eta} \quad (1)$$

where:

- c is the mass concentration of ethylene oxide in the ambient air in mg/m^3
- m is the mass of 2-bromoethanol in the analytical sample in μg
- f is the conversion factor of 2-bromoethanol to ethylene oxide = 0.352
- V is the air sample volume in litres
- η is the recovery (see Section 6.1)

6 Reliability of the method

6.1 Precision and recovery

The precision in the lowest measurement range according to DIN EN 482 (DIN 2021) as well as the recovery rates for three concentrations (see Table 2) were determined. The sample carriers were spiked with the solutions described below:

Validation stock solution: Solution of 0.44 mg of ethylene oxide per ml of toluene

The validation stock solution is prepared by placing 10 ml of toluene into a N10 glass vial and sealing the vial with a crimp cap with septum. A withdrawal station with a septum is used to transfer the ethylene oxide from the pressurised gas cylinder. After piercing the septum, the plunger of the 2.5 ml headspace glass syringe is retracted over the “purging aperture” so that ethylene oxide flows through the syringe and purges it. Then a total of 2.5 ml of ethylene oxide are slowly injected into the gaseous phase of the N10 glass vial after piercing the septum. When this procedure is carried out, the needle of the syringe must not come into contact with the solvent, as solvent adheres to it, which falsifies the subsequent weighing of the added gas. The ethylene oxide dissolved in toluene is weighed exactly to the nearest 0.1 mg and the glass vial is then shaken.

Validation Solution 1: Solution of 4.4 μg of ethylene oxide per ml of toluene

A pipette is used to add 1 ml of the validation solution into a 100 ml volumetric flask into which several ml of toluene have been previously placed. The flask is filled to the mark with toluene and shaken.

Validation Solution 2: Solution of 44 μg of ethylene oxide per ml of toluene

A pipette is used to add 1 ml of the validation solution into a 10 ml volumetric flask into which several ml of toluene have been previously placed. The flask is filled to the mark with toluene and shaken.

While the pump was operating, the activated charcoal tubes were directly spiked with 25 μl of validation solution 1 or 25 and 50 μl of validation solution 2 in each case and then air is drawn through the tubes at a flow rate of 25 ml/min

for 4 hours. The experiment was conducted six times for each amount applied. The spiked amounts of the ethylene oxide were equivalent to the concentrations in air listed in Table 2 at an air sample volume of 6 l.

The samples were prepared and analysed as described in Section 4.

The standard deviations and recoveries determined are shown in Table 2.

Tab.2 Characteristics of the validation

Spiked volumes (validation solution) [μl]	Spiked mass [μg]	Concentration in the air sample [mg/m ³] ^{a)}	Recovery	Relative standard deviation [%]
25 (Val 1)	0.11	0.018	0.99	3.1
25 (Val 2)	1.1	0.183	0.92	0.8
50 (Val 2)	2.2	0.366	0.98	1.0

^{a)} based on a desorption volume of 3 ml and an air sample volume of 6 l

The method was tested up to an air sample volume of 12 l. No breakthrough onto the second tube connected downstream was observed at a concentration of 0.2 mg/m³ of ethylene oxide.

6.2 Limit of quantification

The detection limit and limit of quantification were calculated from the measurement signal/noise level ratio of the baseline. In this case a signal/background noise ratio of 10 was used as a basis for determining the limit of quantification.

The absolute limit of quantification per tube for ethylene oxide is 0.04 μg. This is equivalent to a relative limit of quantification of 0.007 mg/m³ at an air sample volume of 6 l and a desorption agent volume of 3 ml.

6.3 Storage stability

Ethylene oxide can be stored in the adsorbed state at room temperature for 24 hours. The recovery for ethylene oxide after a storage period of 24 hours was 94%.

6.4 Selectivity

Interference by other compounds is eliminated to a large extent by derivatisation and gas chromatographic separation combined with mass-selective detection.

6.5 Uncertainty

The expanded uncertainty was determined taking all relevant influencing factors into consideration as stipulated in DIN EN 482 (DIN 2021). The uncertainty of the entire method and thus also of the analytical result consists principally of the uncertainty contributions of sampling (e.g. air sample volume) and the analytical preparation (complete desorption, scatter of the calibration function, fluctuation in the recoveries and the reproducibility). The expanded uncertainty is between 20% and 21% for the three validation concentrations.

Notes

Competing interests

The established rules and measures of the Commission to avoid conflicts of interest (www.dfg.de/mak/conflicts_interest) ensure that the content and conclusions of the publication are strictly science-based.

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