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Indoor air

Part 29: Test methods for VOC detectors

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National foreword

This British Standard is the UK implementation of ISO 16000-29:2014.

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Part 29:
Test methods for VOC detectors

Air intérieur —

Partie 29: Méthodes d’essai pour détecteurs de composés organiques volatils (COV)

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ISO copyright office
Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.org
Web www.iso.org

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

The committee responsible for this document is ISO/TC 146, *Air quality*, Subcommittee SC 6, *Indoor air*.

ISO 16000 consists of the following parts, under the general title *Indoor air*:

- *Part 1: General aspects of sampling strategy*
- *Part 2: Sampling strategy for formaldehyde*
- *Part 3: Determination of formaldehyde and other carbonyl compounds in indoor air and test chamber air — Active sampling method*
- *Part 4: Determination of formaldehyde — Diffusive sampling method*
- *Part 5: Sampling strategy for volatile organic compounds (VOCs)*
- *Part 6: Determination of volatile organic compounds in indoor and test chamber air by active sampling on Tenax TA® sorbent, thermal desorption and gas chromatography using MS or MS-FID*
- *Part 7: Sampling strategy for determination of airborne asbestos fibre concentrations*
- *Part 8: Determination of local mean ages of air in buildings for characterizing ventilation conditions*
- *Part 9: Determination of the emission of volatile organic compounds from building products and furnishing — Emission test chamber method*
- *Part 10: Determination of the emission of volatile organic compounds from building products and furnishing — Emission test cell method*
- *Part 11: Determination of the emission of volatile organic compounds from building products and furnishing — Sampling, storage of samples and preparation of test specimens*
- *Part 12: Sampling strategy for polychlorinated biphenyls (PCBs), polychlorinated dibenzo*-p-*dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs) and polycyclic aromatic hydrocarbons (PAHs)*

- *Part 13: Determination of total (gas and particle-phase) polychlorinated dioxin-like biphenyls (PCBs) and polychlorinated dibenzo-*p*-dioxins/dibenzofurans (PCDDs/PCDFs) — Collection on sorbent-backed filters*
- *Part 14: Determination of total (gas and particle-phase) polychlorinated dioxin-like biphenyls (PCBs) and polychlorinated dibenzo-*p*-dioxins/dibenzofurans (PCDDs/PCDFs) — Extraction, clean-up and analysis by high-resolution gas chromatography and mass spectrometry*
- *Part 15: Sampling strategy for nitrogen dioxide (NO_2)*
- *Part 16: Detection and enumeration of moulds — Sampling by filtration*
- *Part 17: Detection and enumeration of moulds — Culture-based method*
- *Part 18: Detection and enumeration of moulds — Sampling by impaction*
- *Part 19: Sampling strategy for moulds*
- *Part 20: Detection and enumeration of moulds — Determination of total spore count*
- *Part 21: Detection and enumeration of moulds — Sampling from materials*
- *Part 23: Performance test for evaluating the reduction of formaldehyde concentrations by sorptive building materials*
- *Part 24: Performance test for evaluating the reduction of volatile organic compound (except formaldehyde) concentrations by sorptive building materials*
- *Part 25: Determination of the emission of semi-volatile organic compounds by building products — Micro-chamber method*
- *Part 26: Sampling strategy for carbon dioxide (CO_2)*
- *Part 27: Determination of settled fibrous dust on surfaces by (SEM) scanning electron microscopy (direct method)*
- *Part 28*: *Determination of odour emissions from building products using test chambers*
- *Part 29: Test methods for VOC detectors*
- *Part 30: Sensory testing of indoor air*
- *Part 31: Measurement of flame retardants and plasticizers based on organophosphorus compounds — Phosphoric acid ester*
- *Part 32: Investigation of buildings for pollutants and other injurious factors — Inspections*

The following parts are under preparation:

- *Part 33: Determination of phthalates with gas chromatography/mass spectrometry (GC-MS)*
- *Part 34: Strategies for the measurement of airborne particles (PM 2,5 fraction)*
- *Part 35: Measurement of polybrominated diphenylether, hexabromocyclododecane and hexabromobenzene*
- *Part 36: Test method for the reduction rate of airborne bacteria by air purifiers using a test chamber*

Introduction

Volatile organic compounds (VOCs) of indoor air diffuse from building materials, bounding agents, furniture, pesticides, and other sources. In such a situation, VOC detectors are expected to be widely used for screening, monitoring indoor VOC concentrations, locating sources, controlling ventilation systems, and so on. Therefore, it is desirable to use highly sensitive VOC detectors that can detect a range of VOCs within a building. Reflecting the situation as such, several VOC detectors are commercially available. This part of ISO 16000 contains important quantitative and technical specifications for VOC testing methods intended to improve the reliability of the VOC detection and realize broader use of VOC detectors.

ISO 16017,[1][2] ISO 12219,[3][4][5][6][7] and ISO 16000-6[9] also focus on volatile organic compound (VOC) measurements.

Indoor air —

Part 29:
Test methods for VOC detectors

1 Scope

This part of ISO 16000 specifies test methods of the performance of VOC detectors that are designed to monitor indoor and living atmosphere VOC concentration as well as to control indoor air quality in portable, mobile, and remote applications. The provisions in this part of ISO 16000 cover VOCs detectors as well as detectors for individual VOCs. This part of ISO 16000 sets out only the requirements applicable to a test method of VOC detectors such as response time, stability, and measuring range.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 61000-4-1, *Electromagnetic compatibility (EMC) — Part 4-1: Testing and measurement techniques — Overview of IEC 61000-4 series*

IEC 61000-4-3, *Electromagnetic compatibility (EMC) — Part 4-3: Testing and measurement techniques — Radiated, radio-frequency, electromagnetic field immunity test*

IEC 61000-4-4, *Electromagnetic compatibility (EMC) — Part 4-4: Testing and measurement techniques — Electrical fast transient/burst immunity test*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
aspirated VOC detector
VOC detectors in which test gas is presented to the VOC sensor(s) in a forced manner (e.g. using a gas sampling pump with a pressure differential to induce test gas flow)

3.2
clean air
air that is free of detectable impurities

Note 1 to entry: For the purposes of this part of ISO 16000, the impurities are VOC, flammable gas, and interfering gas.

3.3
diffusion type VOC detector
VOC detector in which the transfer of VOC gas from the atmosphere to the gas sensor takes place by random molecular movement, i.e. under conditions in which there is no aspirated flow

3.4
final indication
adjudged or displayed stable indication

Note 1 to entry: For the purposes of this part of ISO 16000, indication is a VOC concentration provided by a VOC detector.

3.5
VOC detector
assembly with an integrated or a remote VOC sensor that is intended to monitor VOCs

3.6
VOC sensing element
component of a VOC sensor that responds to variation in VOC concentration

3.7
VOC sensor
assembly, which contains the VOC sensing element and can also contain circuit components associated with the VOC sensing element

3.8
interferent
any substance that adversely affects the detection accuracy

Note 1 to entry: For the purposes of this part of ISO 16000, detection accuracy is for final indication of a VOC detector.

3.9
poisoning
phenomenon caused by any interferent that permanently affects the sensitivity of a sensing element

Note 1 to entry: For the purposes of this part of ISO 16000, the sensing element is used for a VOC detector.

3.10
stabilization
state in which three successive readings of a VOC detector indicate no change greater than 10 % of the concentration of the test gas

3.11
test gas
mixture of clean air with a known concentration of one or more VOCs

Note 1 to entry: For the purposes of this part of ISO 16000, test gas is used for performance testing of a VOC detector.

3.12
volatile organic compound
VOC
organic compound whose boiling point is in the range from (50 °C to 100 °C) to (240 °C to 260 °C)

Note 1 to entry: This classification has been defined by the World Health Organization.

Note 2 to entry: Boiling points of some compounds are difficult or impossible to determine because they decompose before they boil at atmospheric pressure. Vapour pressure is another criterion for classification of compound volatility that can be used for classification of organic chemicals.

3.13
warm-up time
time interval between the time when the apparatus is switched on and the time when the apparatus is ready to measure

Note 1 to entry: For the purposes of this part of ISO 16000, the apparatus is a VOC detector.

4 Principle

VOC detectors are designed to detect one or more VOCs as target compounds. Test methods for assessing the performance of VOC detectors are defined. VOC detectors are classified into two categories; one is for specific VOC detection and the other for VOC mixtures (VOCs). In the case of the specific VOC detector, the target VOC concentration is provided upon testing of a standard test gas containing the VOC as one component. The component of standard test gas for VOC mixture detectors has been determined experimentally as described in Annex C. To improve the reliability of VOC detectors, this part of ISO 16000 sets out test methods of VOC detectors which also evaluate response time, stability, poisoning, and so on.

There are several types of VOC detectors with different detection principles such as semiconducting type, PID type, and interference-enhanced reflection type detectors. The principle of operation of the semiconducting type detector depends upon changes of electrical conductance that occur by chemisorption on the surface of the heated sensing element when exposed to gas other than air. Gas concentrations are inferred by measuring the change of resistance. In the PID type detector, the detection principle is based on ionization of gases by ultraviolet radiation from a special lamp of known wavelength, and hence photon energy, usually quoted in electronvolts (e.g. 10,6 eV). The PID type detector can detect most of VOCs. Ionization potential of various substances can be found in the literature or a list can be obtained from the apparatus supplier. The detection principle of the interference-enhanced reflection type detector is based on the adsorption of VOCs into polymer film. The swelling of the polymer film makes the film thickness increase. This change of the film thickness is detected by reflectivity using LED light.

NOTE The concentration given by each detector type when exposed to mixtures in an environment is not equivalent because of the different nature of the detection principles. Even if each detector is calibrated against the same calibration gas mixture, it would not result in equivalency for environmental measurement. The VOC mixture concentration from any such detector would not be equivalent to the TVOC or TVOC SUM values defined in ISO 16000-6.

5 Test

5.1 Requirements for tests

5.1.1 Number of samples

The tests shall be carried out on one VOC detector. Another VOC detector can be used for the poisoning test (see 5.4.10).

5.1.2 Sequence of tests

The drop test shall be performed at the beginning of the test sequence. Other tests specified in 5.4 shall be carried out in a sequence to be defined by the organization performing the tests.

5.1.3 Preparation of the VOC detector before testing

The VOC detector shall be prepared and mounted in a manner representative of the typical application, in accordance with the instruction manual, including all necessary interconnections, initial adjustments, calibration, and warm-up time. In order to keep the detector condition appropriate, the calibration and adjustments, including zero adjustment and span adjustment, can be carried out, where necessary, at the beginning of each test.

a) Battery-powered detectors: When an indication of low battery condition is provided for detectors powered with integral batteries, the nature and purpose of this indication shall be checked in the manual.

b) Software-controlled detectors: In software-controlled detectors, the risks arising from faults in the program shall be taken into account including conversion and data transmission errors.

5.1.4 Performance requirements

The guidelines of the performance requirements specified in the test are indicated in Annex A.

5.2 Test equipment

Mask-type, flow-type, or chamber-type gas delivery equipment is recommended in Annex B. Alternative equipment can also be used. The test procedure specific to each test method shall be followed. When a mask is used for the injection of test gas into the detector, the design and operation of the mask (in particular, the pressure and velocity inside the mask) shall not inadmissibly influence the response of the detector or the results obtained.

A chamber that can be sealed with controlled conditions of temperature, humidity, and test gas concentration shall be used. A chamber shall be made of materials not prone to appreciable absorption and desorption of VOCs such as stainless steel. The type of test equipment shall be described when the results of the tests are indicated in a specification sheet.

It is recommended that the testing laboratory should consult with the manufacturer in determining the design of the mask. The manufacturer should provide a suitable mask together with details of suggested pressure or flow for application of the test gases with the VOC detector. Any other methods specified in an International Standard or Technical Specification should be used, provided that such methods are demonstrated independently for their validity.

5.3 Conditions for standard response test

5.3.1 Temperature

Unless otherwise specified, the tests shall be carried out at a temperature within 20 °C ± 5 °C and the temperature variation shall not cross over 20 °C ± 5 °C throughout the duration of each test.

5.3.2 Pressure

Unless otherwise specified, the tests shall be performed at pressures between 86 kPa and 108 kPa and the pressure shall be kept constant within ±1 kPa throughout the duration of each test.

5.3.3 Humidity

Unless otherwise specified, the tests shall be carried out at a relative humidity (RH) within 50 % ± 30 % and the RH shall be maintained constant within ±10 % throughout the duration of each test.

5.3.4 Voltage

Unless otherwise specified, commercial-powered and given DC-powered VOC detectors shall be operated within 2 % of the manufacturer’s recommended supply voltage and frequency in the case of commercial power.

Battery-powered detectors shall be equipped with new or fully charged batteries at the commencement of each series of tests.

5.3.5 Orientation

The VOC detectors shall be tested in the orientation recommended by the manufacturer indicated in an instruction manual.

5.4 Test methods

5.4.1 Standard response test

5.4.1.1 Standard test gas

The composition of the standard test gas shall be as follows.

a) Detectors for VOC mixtures:

  1) gas component [types i) and ii) are detectors with high sensitivity; type iii) is a detector with low sensitivity]:

    i) semiconducting type: VOC mixed gas of *n*-octane and xylene;

    ii) PID type: VOC mixed gas of toluene, *n*-decane, α-pinene, and methyl isobutyl ketone;

    iii) interference-enhanced reflection type: VOC mixed gas of toluene, *n*-decane, α-pinene, methyl isobutyl ketone, *p*-dichlorobenzene, and butyl acetate;

  2) gas concentration: For all types of detectors, the total concentration of each gas component shall be 300 µg/m^3. Each gas component in the standard test gas shall have the same concentration. If this is not possible due to instrument limitations, gas concentration shall be set as low as possible for the measuring range of the VOC detectors.

b) Detectors for individual VOCs:

  1) gas component: target gas indicated in specification sheet of the VOC detector;

  2) gas concentration: one-fourth of the calibration gas concentration specified by manufacturer, however below 1 mg/m^3.

Choose the detector in function of the gas components being measured. Apply the criteria for the selection of test gases in Annex C.

The uncertainty of the test gas concentration shall not exceed 5 %. The standard test gas can be supplied e.g. by cylinder gas or diffusion tube method (see Annex D) or permeation tube method.

NOTE Gas concentration is expressed as the mass of VOCs included in a volume of 1 m^3 under standard conditions of temperature and pressure of 20 °C and 101,325 kPa.

5.4.1.2 Procedure

The VOC detector shall be exposed to clean air until stable test conditions indicated in 5.3.1, 5.3.2, and 5.3.3 are achieved. The indication shall be recorded as the offset value. The atmosphere shall be changed to the standard test gas, and the final indication shall be recorded.

5.4.2 Validation of accuracy

After the calibration and adjustment of 5.1.3, the VOC detector shall be exposed to the gas with a composition in accordance with 5.4.1.1 at four gas concentrations evenly distributed over the measuring range defined by the lowest and highest measurable concentration, starting with the lowest and finishing with the highest of the selected gas concentrations. This operation shall be carried out three times consecutively.

5.4.3 Stability test

5.4.3.1 Short-term stability test

For these tests, a battery-powered VOC detector should be powered from internal batteries wherever possible. Otherwise, an external power supply can be used.

The standard response test of 5.4.1 shall be carried out five times consecutively with the interval of 900 s. At the end of each test, the final indication for the test gas shall be collected.

The variation of the final indication for the test gas should not exceed ±20 % of the indication.

5.4.3.2 Drift test

The VOC detector shall be operated continuously in clean air for a period of 8 h. Zero time shall be defined as the end of the warm-up period. At zero time and at the end of every 2 h thereafter, the standard response test in 5.4.1 shall be carried out and the final indication for the test gas shall be recorded.

The variation of the final indication for the test gas should not exceed ±20 % of the indication.

5.4.4 Temperature test

This test shall be performed in a test chamber capable of maintaining the ambient temperature surrounding the VOC detector within ±2 °C of the specified temperature. When the temperature inside the test chamber including the VOC detector has reached the specified temperature and stabilized, the VOC detector shall be subjected to the standard response test of 5.4.1 with exception of temperature using clean air and a test gas at the same temperature as the atmosphere in the test chamber. In order to avoid condensation, the dew point of the clean air or the test gas shall be below the lowest temperature of the test chamber and kept constant during the test. The VOC detector shall be tested at 5 °C, 20 °C, and 40 °C.

The variation of the final indication obtained from the test at each specific temperature from that obtained at 20 °C should not exceed ±20 % of the indication.

5.4.5 Pressure test

The effects of pressure variation shall be observed by placing the VOC detector in a test chamber that permits the pressure of the atmosphere to be varied.

The test shall be performed under condition of 5.3 with exception of pressure. The standard response test of 5.4.1 shall be carried out at pressures of 100 kPa, 80 kPa, and 110 kPa with a tolerance of ±3 kPa. The pressure shall be maintained at the specified levels for 5 min before starting each test.

The variation of the final indications at 80 kPa and 110 kPa from the final indication at 100 kPa should not exceed ±20 % of the indication.

5.4.6 Humidity test

The test shall be performed under condition of 5.3 with exception of humidity. The standard response test of 5.4.1 shall be carried out at a relative humidity of 20 %, 50 %, and 80 % with uncertainty not larger than 3 %. The VOC detector shall be allowed to first stabilize at 20 °C ± 2 °C and a relative humidity of 50 %. For each humidity level, the VOC detector shall be exposed for 15 min or longer to clean air and then to the test gas at the same humidity.

The variation of the final indications at relative humidity of 20 % and 80 % from the final indication at a relative humidity of 50 % should not exceed ±30 % of the indication.

5.4.7 Air velocity test

This test shall be carried out for diffusion type detectors. The effects of air velocity shall be evaluated by placing the VOC detector in a flow chamber suitable for the application of clean air and the test gas. The gas inlet of the VOC detector shall be oriented in relation to the direction of the airflow as follows:

a) sensor oriented directly in the direction of flow;

b) sensor oriented away from the direction of flow;

c) sensor oriented at right angles to the direction of flow.

Directions of flow that are expressly prohibited in the manufacturer's instruction manual shall be exempted from the test. Directions of flow that are not likely to occur in practice, due to the design of the VOC detector, can be exempted from the test. All exemptions shall be documented in the test report.

The standard response test described in 5.4.1 shall be carried out and the final indication for the test gas shall be recorded. Measurements shall be taken under conditions at air velocities of 0,3 m/s and at 0,1 m/s with a tolerance of ±0,05 m/s.

The variation of the final indication at 0,3 m/s and 0,1 m/s air velocity from the final indication under zero air velocity should not exceed ±20 % of the indication.

5.4.8 Test for time of response and time of recovery

The VOC detector shall be subjected to step changes from clean air to the standard test gas and from standard test gas to clean air. The time of response t(90) and the time of recovery t(10) shall be measured. The data collecting interval should be less than 2 s to evaluate t(90) and t(10). Results from testing a VOC detector without a memory or an output terminal shall be documented by another means such as video recording.

The time of response t(90) should be 300 s or less. The time of recovery t(10) shall be 600 s or less.

NOTE 1 Time of response t(90) is the time interval, with the VOC detectors in a measureable condition, between the time when an instantaneous variation from clean air to the standard test gas is produced at the inlet of the remote VOC sensor or the VOC detectors with an integrated VOC sensor and the time when the response reaches 90 % of the final indication.

NOTE 2 Time of recovery t(10) is the time interval, with the VOC detectors in a measureable condition, between the time when an instantaneous variation from the standard test gas to clean air is produced at the inlet of the remote VOC sensor or the VOC detectors with an integrated VOC sensor and the time when the response reaches a stated percentage (10 %) of the final indication for the standard test gas.

5.4.9 Interferent test

The sensitivity of the VOC detector to other gases shall be evaluated using the test procedure specified in 5.4.1 except that carbon dioxide of 2 800 mg/m^3 ± 140 mg/m^3 shall be added to the test gas.

PID type detectors can skip the interferent test for carbon dioxide. When interferent gases and their appropriate concentrations are listed by the manufacturer, the response of the VOC detector shall be tested for these gases.

The final indication for the carbon dioxide should not exceed 20 % of the final indication of the standard response test.

5.4.10 Poisoning test

The VOC detector in working condition shall be exposed to hexamethyldisiloxane (HMDSO) of $6{,}6 \times 10^4$ μg/m^3 ± $2{,}2 \times 10^4$ μg/m^3 for 60 min. Tests for HMDSO can be carried out with dry gas. When poisoning gases and their appropriate concentrations are listed by the manufacturer, poisoning test shall be carried out for these gases.

After the 60 min period, the VOC detector in working condition shall be exposed to clean air for 60 min followed by the standard response test of 5.4.1.

The variation of the final indication of the standard response test after the poisoning test from the final indication of the standard response test before the poisoning test should not exceed ±20 % of the indication.

5.4.11 Operation above the measuring range test

The VOC detector in working condition shall be exposed to the test gas with the same gas component as the standard test gas. The concentration of the test gas shall be 1,5 times higher than the upper limit of the measuring range for 3 min, unless otherwise the concentration does not exceed the lower explosive limit. The VOC detectors shall then be subjected to clean air for 20 min followed by the standard response test of 5.4.1.

The variation of the final indication of the standard response test after the operation above the measuring range test from the final indication of the standard response test before the operation above the measuring range test should not exceed ±20 % of the indication.

5.4.12 Drop test

Before and at the conclusion of the test, the detectors shall be exposed to clean air followed by the standard response test of 5.4.1. The packaged detectors shall be released from a height of 1 m (mobile type) or 0,3 m (portable type) above a concrete surface and allowed to free fall. If the manufacturer recommends that the detector be used in its carrying case, the test shall be carried out with the case.

5.4.13 Vibration test

5.4.13.1 Test equipment

The vibration test machine shall consist of a vibrating table capable of producing a vibration of variable frequency and variable displacement (peak-to-peak), with the test detectors mounted in place, as required by the following test procedures.

5.4.13.2 Procedures

The packaged detector shall be mounted on the vibration table in the same manner as intended for service use including any resilient mounts and carrier or holding devices that are provided as standard parts of the detectors.

The packaged detector shall be energized and mounted on the vibration test machine and vibrated successively in each of three planes respectively parallel to each of the three major axes of the detectors. The packaged detectors shall be vibrated over the frequency range specified at the excursion or constant acceleration peak specified in 5.4.13.3, for a period of 1 h in each of the three mutually perpendicular planes. The rate of change of frequency shall not exceed 10 Hz/min. Before and at the conclusion of the test, the standard response test of 5.4.1 shall be carried out.

5.4.13.3 Vibration levels

For packaged detectors, the vibration shall be as follows:

— 10 Hz to 30 Hz, 1,0 mm total excursion;

— 31 Hz to 150 Hz, 19,6 m/s^2 acceleration peak.

5.4.14 Power supply variations test

The VOC detector shall be set up under the normal conditions specified in 5.3, at nominal supply voltage that is given by the manufacturer as the recommended operating voltage of the VOC detectors and, where appropriate, rated frequency. The standard response test of 5.4.1 shall be carried out at both 80 % of the lowest nominal supply voltage and 115 % of the highest nominal supply voltage.

Where the manufacturer of the VOC detector specifies a supply voltage range other than those specified above, the VOC detector shall be tested at the upper and lower limits of the supply voltage specified by the manufacturer.

Battery-powered detectors can omit the power supply variations test.

The variation of the final indications at 80 % and 115 % of the nominal supply voltage from the final indication at the nominal supply voltage should not exceed ±20 % of the indication.

5.4.15 Electrical fast transient test

The VOC detector shall be set up under the normal conditions specified in 5.3. The VOC detectors shall be tested according to IEC 61000-4-4, test severity 2. The test procedure for type test shall be used. The test duration shall be 1 min for each line or terminal to be tested. The VOC detectors shall be subjected to this test in clean air.

5.4.16 Electromagnetic field test

The VOC detector shall be subjected to the test method used in the EMC radiated immunity tests specified in IEC 61000-4-1 and IEC 61000-4-3. The test requirements shall be carried out with severity level 2 and test field strength of 3 V/m.

5.4.17 Battery capacity test

With a battery fully charged at the beginning of the test, the detectors shall be operated in clean air for a total period of

a) 8 h, if fitted with a user-operable on/off switch,

b) 10 h, if not so fitted, or

c) any longer time as specified by the manufacturer.

At the end of the specified period, the standard response test of 5.4.1 shall be carried out.

6 Test report

Each test report shall include at least the following information, unless the laboratory has valid reasons for not providing such:

a) a title;

b) the name and address of the laboratory;

c) unique identification of the test report (such as the serial number), and on each page an identification in order to ensure that the page is recognized as a part of the test report, and a clear identification of the end of the test report;

d) the name and address of the customer;

e) identification of the method used;

f) a description of, the condition of, and unambiguous identification of the item(s) tested;

g) the gas component(s) and concentration of used test gas;

h) the test procedure;

i) the date of receipt of the test item(s) where this is critical to the validity and application of the results;

j) the test results;

k) the name(s), function(s), and signature(s) or equivalent identification of person(s) authorizing the test report.

Hard copies of test reports should also include the page number and total number of pages.

Annex A
(informative)

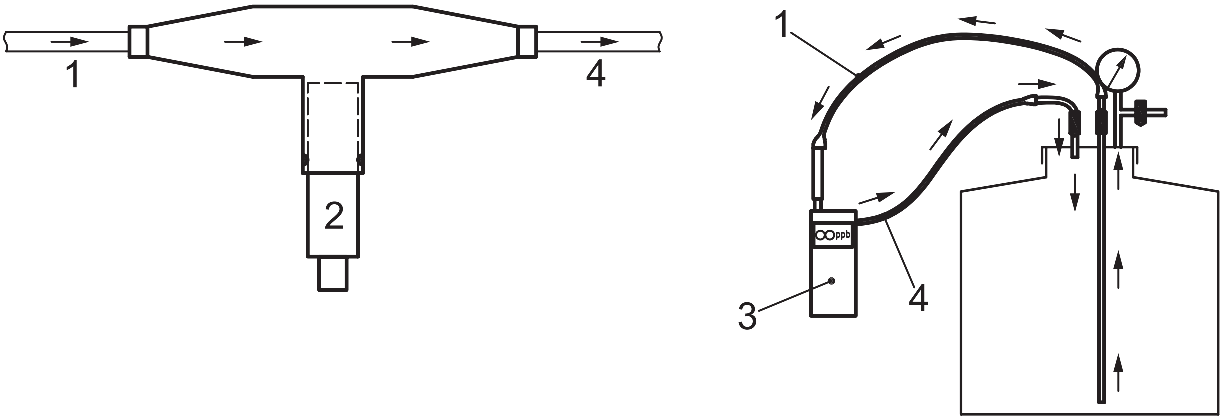
Overview of performance requirements

Table A.1 — Performance requirements

Subclause	Test	Apparatus limits
5.4.3.1	Short-term stability test	variation of final indication: ±20 % of indication
5.4.3.2	Drift test	variation of final indication: ±20 % of indication
5.4.4	Temperature test	±20 % of indication from 20 °C (test 5 °C, 20 °C, 40 °C)
5.4.5	Pressure test	±20 % of indication from 100 kPa (test 80 kPa, 100 kPa, 110 kPa)
5.4.6	Humidity test	±30 % of indication from 50 % RH (test 20 % RH, 50 % RH, 80 % RH)
5.4.7	Air velocity test	±20 % of indication from 0 m/s (test 0,3 m/s, 0,1 m/s)
5.4.8	Test for time of response and time of recovery	t(90) in less than 300 s, t(10) in less than 600 s
5.4.9	Interferent test	variation of final indication for the test gas: less than 20 % of final indication of standard response test
5.4.10	Poisoning test	variation of final indication after the test: ±20 % of indication
5.4.11	Operation above the measuring range test	variation of final indication after the test: ±20 % of indication
5.4.14	Power supply variations test	±20 % indication from 100 % nominal supply voltage (test 80 %, 100 %, 115 %)

Annex B
(informative)

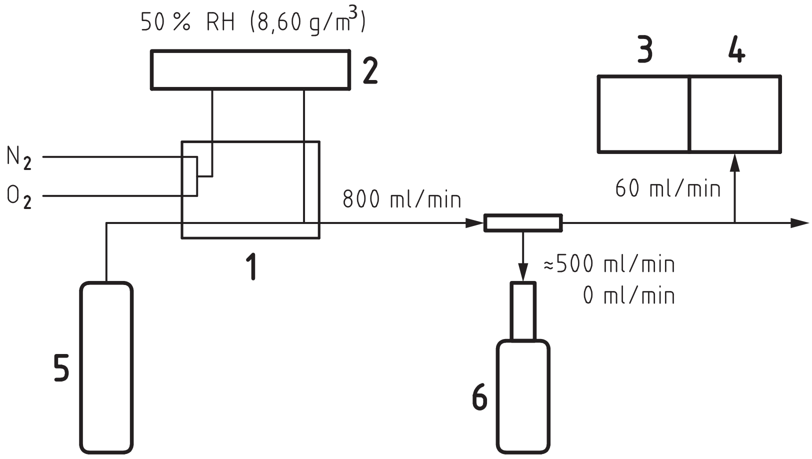
Test equipment



Key

1	gas in
2	sensor probe
3	VOC detector
4	gas out

Figure B.1 — Mask type (left), chamber type (right)



Key

1 gas mixture

2 humidifier, equipped with a thermal controller, which controls the saturated water vapour pressure to maintain 20 %, 50 %, or 80 % RH at the standard temperature (20 °C)

3 GC-MS

4 gas condenser

5 gas cylinder or gas generation system

6 VOC detector (semiconductor detector, photoionization detector, interference-enhanced reflection detector)

Figure B.2 — Flow type

Annex C
(normative)

Selection of test gas

C.1 VOC detectors

This study was performed on three typical VOC detectors to determine the optimal test gas constituents for each of them. Three typical VOC detectors of different detection principles (metal oxide semiconductor, PID, and IER) were used.

- High sensitive detector:
  - metal oxide semiconductor: Handy TVOC monitor FTVR-01[1];
  - PID: ppbRAE3000[2], equipped with 10,6 eV UV lamp.
- Low sensitive detector:
  - IER: Handy VOC sensor VOC-121H[3].

Table C.1 shows the important specifications of the three detectors. The basic properties of these detectors, such as detection limit, resolution, accuracy, temperature, and humidity, were not verified in this study. Therefore, the gas sensing properties measurement conditions, i.e. temperature and humidity, were kept constant according to the specifications of the portable detectors, as described in C.4. The metal oxide semiconductor and PID detectors can monitor to home and office VOC levels (up to $4,1 \times 10^3$ μg/m^3; toluene equivalent) and a work environment VOC level (up to $4,1 \times 10^4$ μg/m^3; toluene equivalent). The IER detector can monitor to the levels found in a work environment. In a study, the metal oxide semiconductor and PID detectors were tested at levels of approximately up to $4,1 \times 10^4$ μg/m^3, and the IER detector was tested at levels between $4,1 \times 10^3$ μg/m^3 and $1,4 \times 10^4$ μg/m^3.

Table C.1 — Important specifications of the three typical VOC detectors

	FTVR-01	**ppbRAE3000**	**VOC-121H**
Principle	Metal oxide semiconductor	PID	IER
Range	auto range — 1 μg/m^3 to 1 000 μg/m^3 — 1 μg/m^3 to 10 000 μg/m^3	auto range — 0 μg/m^3 to $2,5 \times 10^4$ μg/m^3 — $2,5 \times 10^4$ μg/m^3 to $2,5 \times 10^5$ μg/m^3 — $2,5 \times 10^5$ μg/m^3 to $2,5 \times 10^6$ μg/m^3 — $2,5 \times 10^6$ μg/m^3 to $2,5 \times 10^7$ μg/m^3 (isobutylene equivalent)	auto range — $4,1 \times 10^3$ μg/m^3 to $4,1 \times 10^5$ μg/m^3 — $1,0 \times 10^5$ μg/m^3 to $1,0 \times 10^7$ μg/m^3 (toluene equivalent)

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[1] Handy TVOC monitor FTVR-01® is an example of a suitable product available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of this product.

[2] ppbRAE3000 ® is an example of a suitable product available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of this product.

[3] Handy VOC sensor VOC-121H is an example of a suitable product available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of this product.

Table C.1 *(continued)*

	FTVR-01	**ppbRAE3000**	**VOC-121H**
Resolution	1 μg/m^3	— 2,5 μg/m^3 — 25 μg/m^3 — 250 μg/m^3 — 2 500 μg/m^3	410 μg/m^3
Accuracy	Not provided	Not provided	±20 % of indication value
Measuring time	1 min	several seconds	10 s to 30 s
Temperature	0 °C to 40 °C	–20 °C to 50 °C	5 °C to 50 °C
Humidity	5 % RH to 95 % RH	0 % RH to 95 % RH	10 % RH to 95 % RH

C.2 Simulated VOC mixed gas

In this study, a simulated VOC mixed gas comprising 31 VOC components was advocated, in broad accordance with Reference [8]. An attempt was made to include each VOC component at the same concentrations because it is difficult to establish typical concentrations in buildings. Table C.2 shows the concentrations of each component in an appropriate simulated gas. The excluded 22 VOCs are represented by chemical homologues, so the concentration of some VOCs is higher than others. There are two limitations to prepare the VOC mixed gas cylinder due to technical reasons: 1) VOC components with low saturated vapour pressures cannot be included in the gas cylinder and 2) the concentration of each VOC component can be controlled increments of the lowest concentration of each VOC, such as 1,7 × 10^3 μg/m^3 of benzene, 3,5 × 10^3 μg/m^3 of *n*-undecane, and 7,8 × 10^2 μg/m^3 of *n*-dodecane. Because of these limitations, 31 kinds of VOC mixed gas has been designed as the simulated VOC mixed gas.

Table C.2 — Component and concentration of the simulated VOC mixed gas into a cylinder

Groups	**Name**	**Concentration** μg/m^3
Aromatic hydrocarbons	Benzene	1,7 × 10^3
	Toluene	2,1 × 10^3
	o-xylene	2,4 × 10^3
	m-xylene	2,4 × 10^3
	Styrene	2,4 × 10^3
	Ethylbenzene	2,4 × 10^3
	n-propylbenzene	2,7 × 10^3
	1,2,3-Trimethylbenzene	2,7 × 10^3
	1,2,4-Trimethylbenzene	2,7 × 10^3
	1,3,5-Trimethylbenzene	2,7 × 10^3
	o-ethyltoluene	2,7 × 10^3
NOTE Balanced gas: nitrogen.		

Table C.2 *(continued)*

Groups	Name	Concentration µg/m^3
Aliphatic hydrocarbons	*n*-hexane	2,0 × 10^3
	2-Methylpentane	2,0 × 10^3
	3-Methylpentane	2,0 × 10^3
	n-heptane	2,3 × 10^3
	2,4-Dimethylpentane	2,3 × 10^3
	n-octane	2,6 × 10^3
	2,2,4-Trimethylpentane	2,6 × 10^3
	n-nonane	2,9 × 10^3
	n-decane	3,2 × 10^3
	n-undecane	3,6 × 10^3
	n-dodecane	7,8 × 10^2
Cycloalkanes	Methylcyclopentane	1,9 × 10^3
	Cyclohexane	1,9 × 10^3
	Methylcyclohexane	2,2 × 10^3
Terpenes	α-pinene	3,1 × 10^3
	β-pinene	3,1 × 10^3
	(+)-Limonene	3,1 × 10^3
Ketones	Methyl isobutyl ketone	1,4 × 10^4
Halogenated hydrocarbons	*p*-dichlorobenzene	3,3 × 10^3
Esters	Butyl acetate	5,2 × 10^3
	Total	9,07 × 10^4
NOTE Balanced gas: nitrogen.		

C.3 Candidates of test gas for VOCs detector

Prospective test gases including a limited number of components have been advocated for PID, semiconductor, and IER detectors. Semiconductor type VOCs sensors to 40 kinds of individual VOCs are reported in References [12] and [13]. It has been reported that the responsibility can be classified into seven kinds of groups, i.e. aromatic hydrocarbon, aliphatic hydrocarbon, terpene, halide, ester, aldehyde, and other oxy hydrocarbon. Therefore, one component from each group in the simulated VOC mixed gas and advocated six kinds of mixed gas as a candidate of the test gas (note that aldehyde is omitted due to a poor stability) were selected, as shown in Table C.3.

For the PID and IER detectors, the "correction factor" for each VOC component is provided. In the case of single target gas monitoring, the product of the indication value and the correction factor should be a real concentration. For both types of detectors, the correction factor of a VOC having the carbon number from six to 16 can be classified into two groups: saturated and unsaturated hydrocarbons (PID; see Figure C.1) and aliphatic and aromatic hydrocarbons (IER detector; see Figure C.2). Therefore, two kinds of mixed gas including *m*-xylene and *n*-octane have been advocated as a candidate of test gas (see Table C.3). In addition, toluene gas has also been another candidate of test gas.

Another candidate of test gases including four kinds of VOCs have been prepared by reducing the two components from the above described six kinds of mixed gas, PM, PB, and MB gases, as shown in Table C.4.

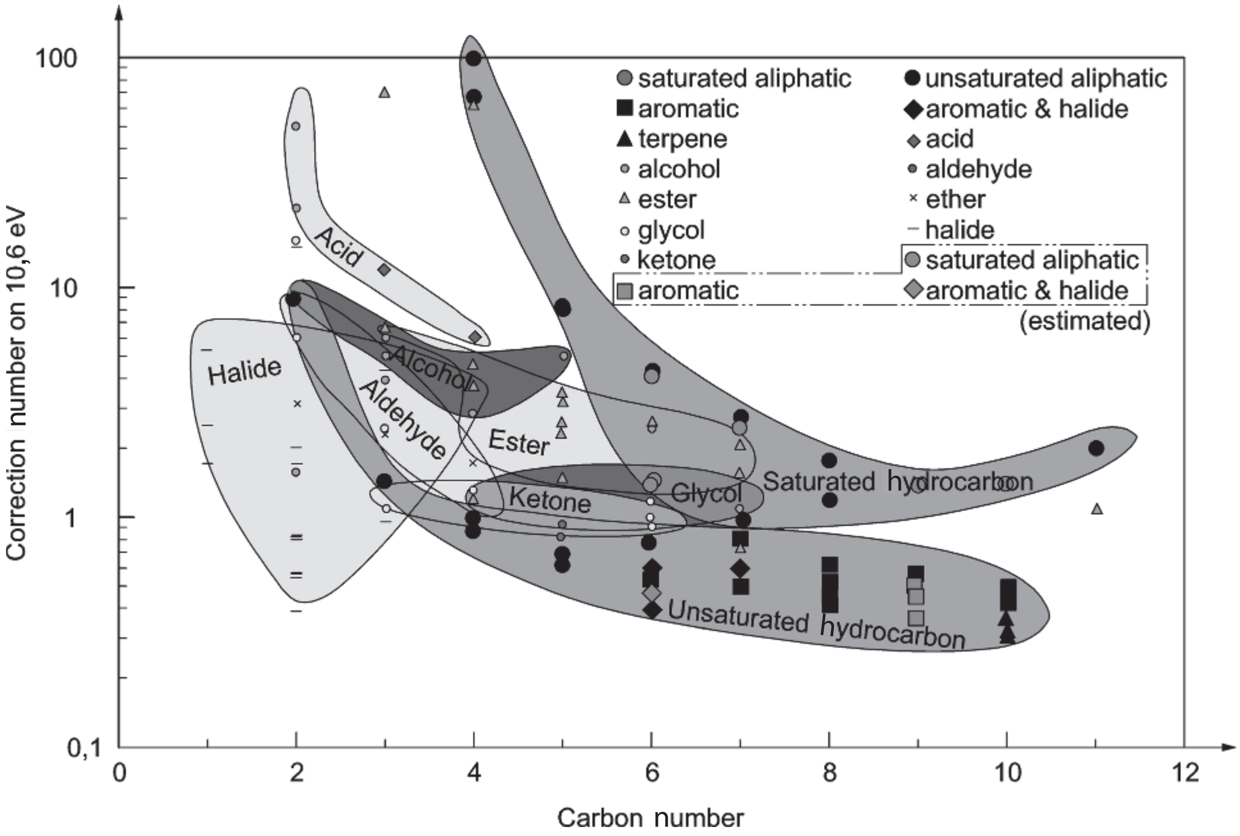
Table C.3 — Component and concentration of the six kinds and two kinds of VOC mixed and toluene gases into cylinders

Groups	Name	Concentration µg/m³
Six kinds of VOC mixed gas		
Aromatic hydrocarbon	Toluene	$1,0 \times 10^4$
Aliphatic hydrocarbon	*n*-decane	$1,6 \times 10^4$
Terpene	*α*-pinene	$1,5 \times 10^4$
Ketone	Methyl *i*-butyl ketone	$1,1 \times 10^4$
Halogenated hydrocarbon	*p*-dichlorobenzene	$1,6 \times 10^4$
Ester	Butyl acetate	$1,3 \times 10^4$
	Total	$8,2 \times 10^4$
Two kinds of VOC mixed gas		
Saturated hydrocarbon Aliphatic hydrocarbon	*n*-octane	$4,2 \times 10^4$
Unsaturated hydrocarbon Aromatic hydrocarbon	*m*-xylene	$3,7 \times 10^4$
	Total	$7,9 \times 10^4$
Toluene gas		
	Toluene	$7,9 \times 10^4$
	Total	$7,9 \times 10^4$
NOTE Balanced gas: nitrogen.		

Table C.4 — Component and concentration of the four kinds of VOC mixed gases, PM, PB, and MB gases, into cylinders

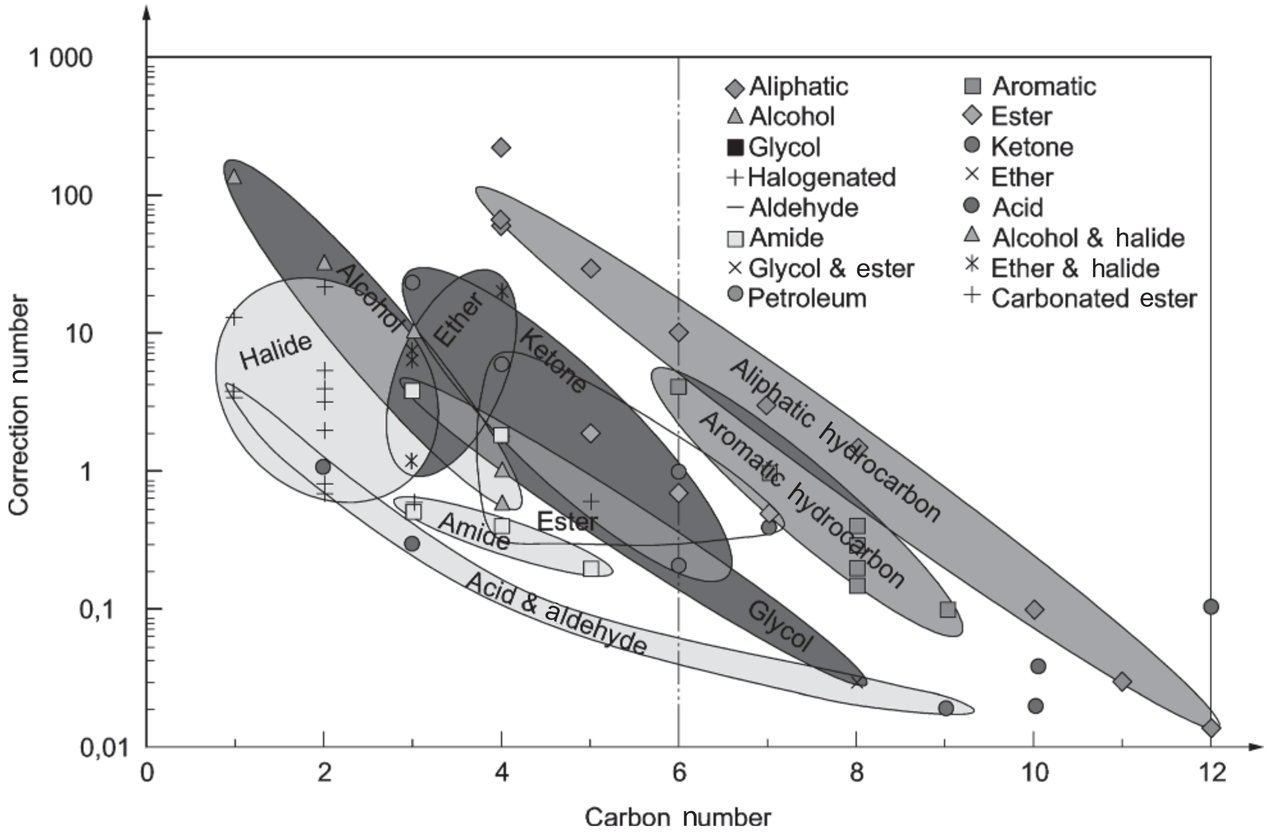
Groups	**Name**	**Concentration** μg/m^3
PM gas		
Aromatic hydrocarbon	Toluene	$1,6 \times 10^4$
Aliphatic hydrocarbon	*n*-decane	$2,5 \times 10^4$
Terpene	*α*-pinene	$2,4 \times 10^4$
Ketone	Methyl *i*-butyl ketone	$1,8 \times 10^4$
	Total	$8,4 \times 10^4$
PB gas		
Aromatic hydrocarbon	Toluene	$1,6 \times 10^4$
Aliphatic hydrocarbon	*n*-decane	$2,5 \times 10^4$
Terpene	*α*-pinene	$2,4 \times 10^4$
Ester	Butyl acetate	$2,1 \times 10^4$
	Total	$8,6 \times 10^4$
MB gas		
Aromatic hydrocarbon	Toluene	$1,6 \times 10^4$
Aliphatic hydrocarbon	*n*-decane	$2,5 \times 10^4$
Ketone	Methyl *i*-butyl ketone	$1,8 \times 10^4$
Ester	Butyl acetate	$2,1 \times 10^4$
	Total	$8,1 \times 10^4$

NOTE Balanced gas: nitrogen.



NOTE All correction factors are plotted against their carbon number.

Figure C.1 — Correction factor of each VOC component on the PID (RAE Systems)

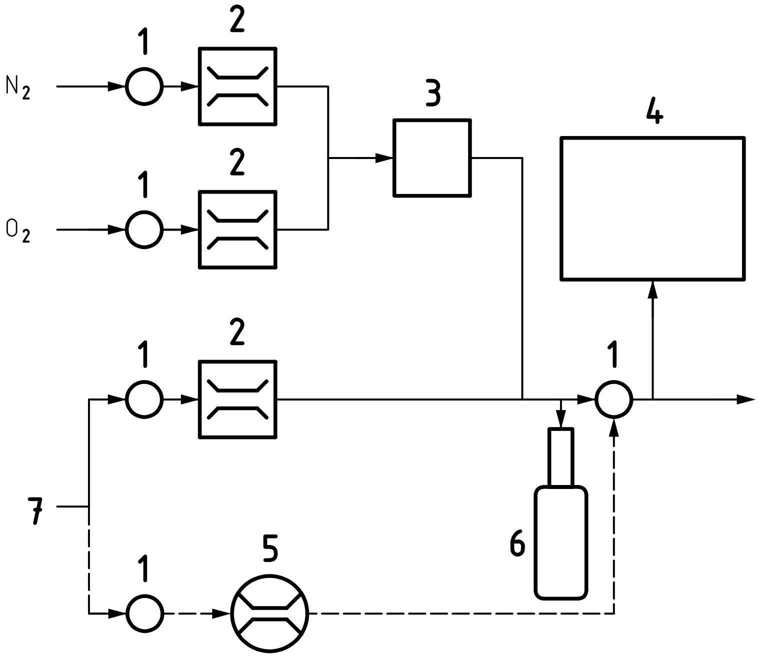


NOTE All correction factors are plotted against their carbon number.

Figure C.2 — Correction factor of each VOC component on the IER detector (O.S.P. Inc.)

C.4 Measurements

VOC detectors were evaluated in a flow apparatus at 24 °C ± 2 °C, as shown in Figure C.3. A water bubbler equipped with thermal controller was used for controlling humidity at 50 % ± 10 %. A tetrafluoroethylene perfluoroalkylvinylether copolymer (PFA) tube was used as a flow pass of downstream from a water bubbler. PTFE (polyterafluoroethene) and stainless tubes were used as other flow passes. Flow rates of nitrogen, oxygen, and VOC gases were controlled by mass flow controllers. A N_2/O_2 ratio was kept always to 4 and a total flow rate was set at 800 ml/min. The GC-MS data were acquired by a GC-MS instrument equipped with a thermal desorption unit. The calibration of the GC-MS was carried out using raw VOC mixed gases from the gas cylinders. The gas sampling rate and time were 60 ml/min and 2 min to 6 min, respectively. The gas sampling was started when the indication value of the portable VOC detectors, which can carry out real-time monitoring, became stable. The concentration values from the GC-MS were converted into toluene equivalents. The indication values from the portable VOC detectors were recorded at the same time as the GC-MS sampling.



Key

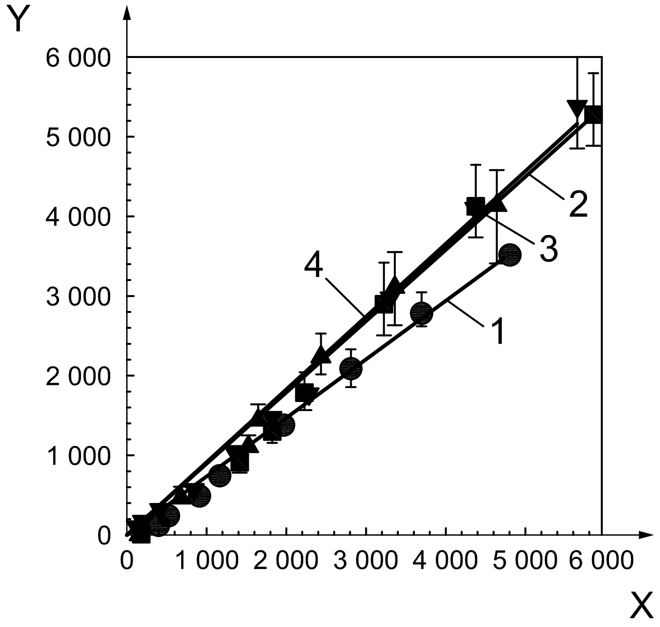
1	valve
2	MFC (mass flow controller)
3	water bubbler
4	GC-MS
5	flow meter with needle valve
6	portable VOC detector
7	VOC gas cylinder

NOTE Dashed lines were used for GC-MS calibration.

Figure C.3 — Schematic diagram of test equipment

C.5 Results of semiconductor detector

Figure C.4 shows the indication of the semiconductor detector to the simulated VOC mixed gas and the candidates of test gases. The difference of indications between the simulated VOC mixed gas and the toluene, the two kinds of VOC mixed, and the six kinds of VOC mixed gases are −18,1 %, −1,6 %, and −0,46 %, respectively. Therefore, the two kinds of VOC mixed and the six kinds of VOC mixed gases are suitable for the test gas. Considering the cost issue, the mixed gas with less components is better. Moreover, error bars of the two and six kinds of VOC mixed gases are larger than the difference between two and six kinds of VOC mixed gases. Therefore, it was concluded that the two kinds of VOC mixed gas is the most suitable test gas for the semiconductor detector.



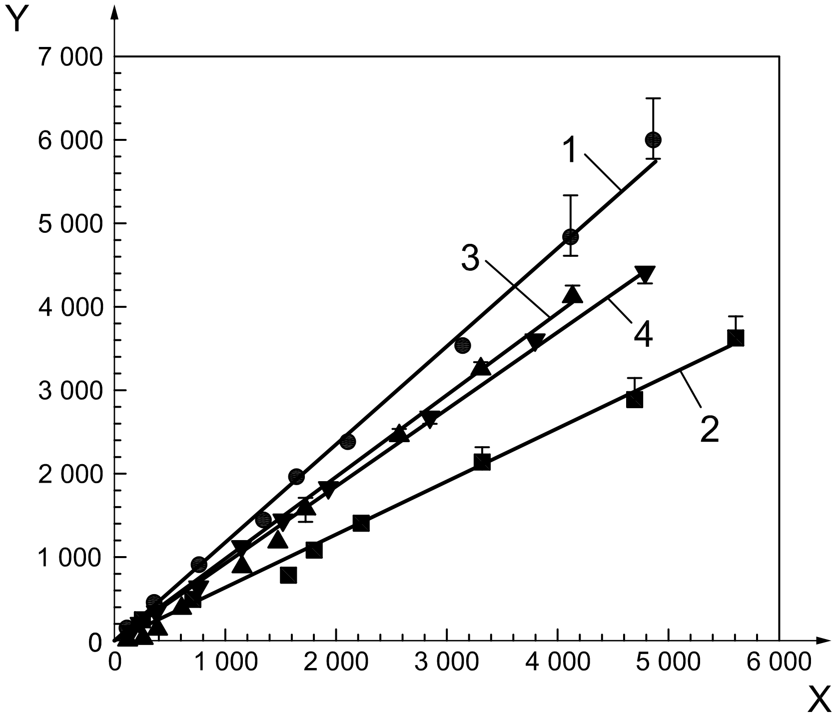
Key

1	toluene
2	six kinds of VOC mixed gas
3	two kinds of VOC mixed gas
4	simulated VOC mixed gas
X	GC-MS (toluene equivalent, µg/m^3)
Y	semiconductor detector (toluene equivalent, µg/m^3)

Figure C.4 — Indication of the semiconductor detector to the simulated VOC mixed gas and the candidates of test gases

C.6 Results of PID

Figure C.5 shows the indication of the PID to the simulated VOC mixed gas and the candidates of test gases. The indication of the PID corresponds to isobutylene equivalent one because the manufacturer recommends isobutylene as a standard calibration gas. The difference of indications between the simulated VOC mixed gas and the toluene, the two kinds of VOC mixed, and the six kinds of VOC mixed gases are 27,9 %, −31,6 %, and 4,9 %, respectively. Therefore, the six kinds of VOC mixed gas is the most suitable test gas.

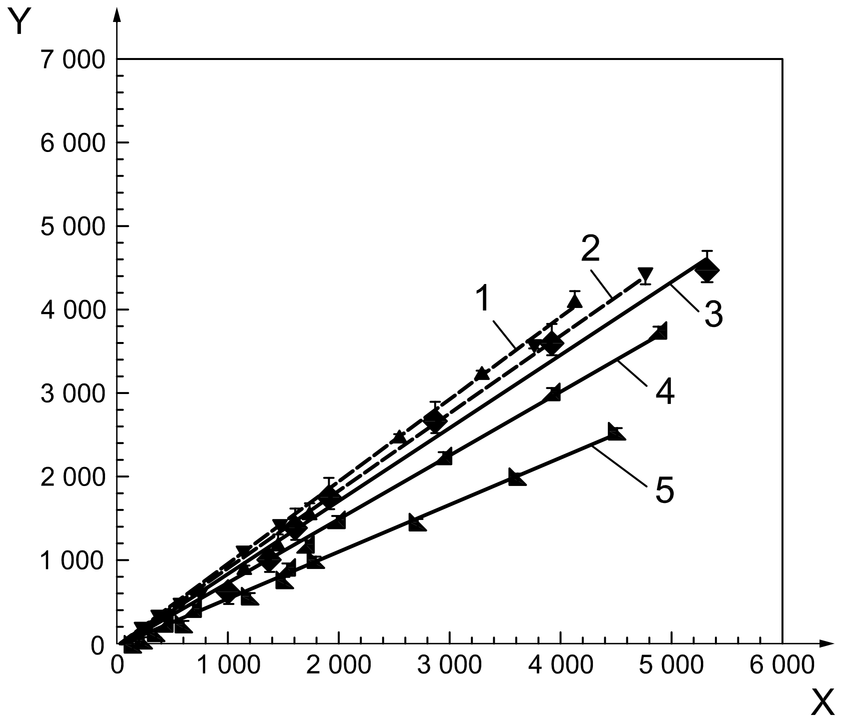


Key

1 toluene
2 two kinds of VOC mixed gas
3 six kinds of VOC mixed gas
4 simulated VOC mixed gas
X GC-MS (toluene equivalent, μg/m^3)
Y PID (isobutylene equivalent, μg/m^3)

Figure C.5 — Indication of PID type detector and GC-MS reference system for different VOC test gas mixtures

Figure C.6 shows the indication of the PID to the PM, PB, and MB gases. The difference of indications between the simulated VOC mixed gas and the PM, PB, and MB gases are −4,2 %, −18,5 %, and −39,7 %, respectively. Therefore, the six kinds of VOC mixed gas is the most suitable test gas. The PM gas is the most suitable test gas among the candidates of the test gases.



Key

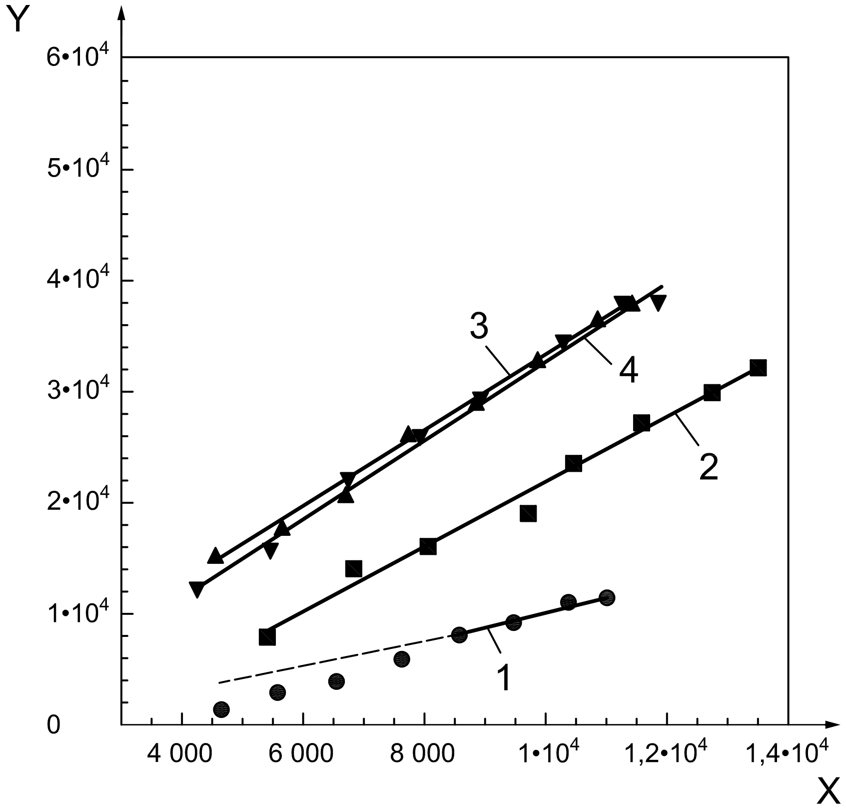
1	six kinds of VOC mixed gas
2	simulated VOC mixed gas
3	PM gas
4	PB gas
5	MB gas
X	GC-MS (toluene equivalent, μg/m^3)
Y	PID (isobutylene equivalent, μg/m^3)

Figure C.6 — Indication of PID type detector and GC-MS reference system for different VOC test gas mixtures and PM, PB, and MB gases

C.7 Results of IER detector

Figure C.7 shows the indication of the IER detector to the simulated VOC mixed gas and the candidates of test gases. The indication of the IER detector corresponds to toluene equivalent one because the manufacturer recommends toluene as a standard calibration gas. The difference of indications between the simulated VOC mixed gas and the toluene, the two kinds of VOC mixed, and the six kinds of VOC mixed gases are −68,7 %, −31,5 %, and 2,3 %, respectively. Therefore, the six kinds of VOC mixed gas is the most suitable test gas.

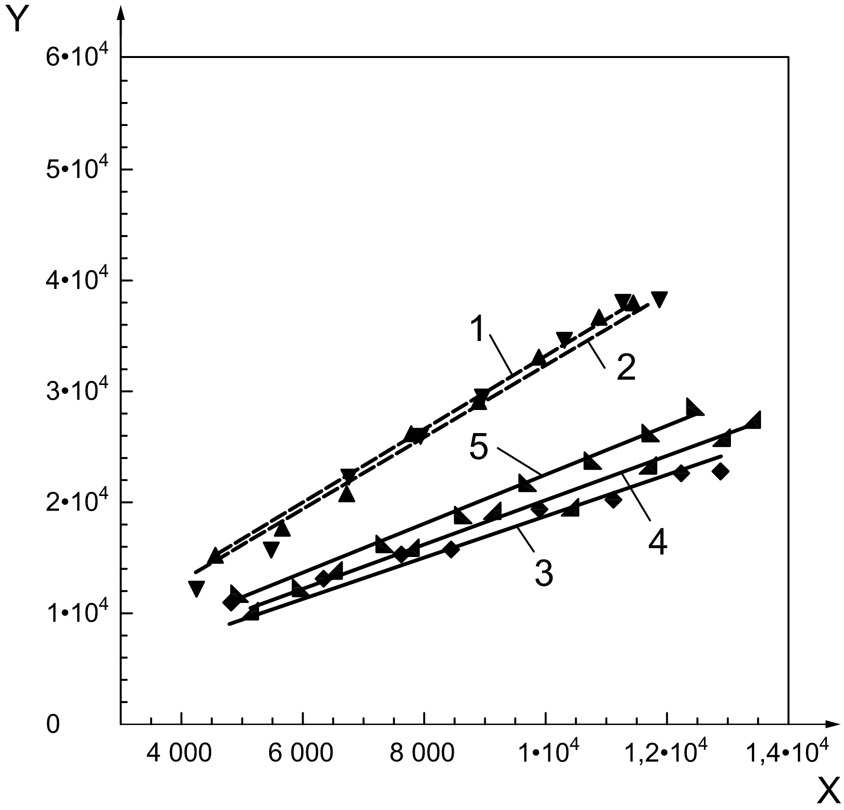
Figure C.8 shows the indication of the PID detector to the PM, PB, and MB gases. The difference of indications between the simulated VOC mixed gas and the PM, PB, and MB gases are −42,2 %, −37,9 %, and −30,9 %, respectively. The indications to all the four kinds of mixed gases are too low compared with those to the six kinds of mixed gas.



Key

1 toluene
2 two kinds of VOC mixed gas
3 six kinds of VOC mixed gas
4 simulated VOC mixed gas
X GC-MS (toluene equivalent, µg/m^3)
Y IER detector (toluene equivalent, µg/m^3)

Figure C.7 — Indication of the IER detector to the simulated VOC mixed gas and the candidates of test gases



Key

1 six kinds of VOC mixed gas
2 simulated VOC mixed gas
3 PM gas
4 PB gas
5 MB gas
X GC-MS (toluene equivalent, µg/m^3)
Y IER detector (toluene equivalent, µg/m^3)

Figure C.8 — Indication of the IER detector to the simulated VOC mixed gas and the PM, PB, and MB gases

C.8 Conclusion

The most suitable constituents of the test gas mixtures for the semiconductor, PID, and IER detectors are as follows:

— semiconductor detector: two kinds of VOC mixed gas (see Table C.3);

— PID: PM gas (see Table C.4);

— IER detector: six kinds of VOC mixed gas (see Table C.3).

Annex D
(informative)

Diffusion tube method

D.1 General

It resulted that the suitable test gas for the metal oxide semiconductor detector is the two kinds of VOC mixed gas (see Table C.3), while a suitable test gas for the PID is the four (PM gas; see Table C.4) and six kinds of VOC mixed gases (see Table C.3), and the test gas for the IER detector is the six kinds of VOC mixed gas, as shown in Annex C. This study has verified the reliability of the diffusion tube method for the evaluation of the portable VOC detectors.

A gas generation equipment has an advantage to generate mixtures of several kinds of VOCs on site. The equipment has its diffusion tubes, which are the vessel of solvents or solids of VOCs. For controlling the generation rate of VOCs, it is important to adjust the tube diameter and height of the diffusion tubes (see Reference [8]).

NOTE The gas generation equipment was verified for the evaluation of the portable VOC detectors. Two alternatives were offered, the gas cylinder and the gas generation equipment, to evaluators of the detectors, because they can select the preparation of the test gas in accordance with the cost, evaluation equipment, period of evaluation, etc.

D.2 VOC detectors

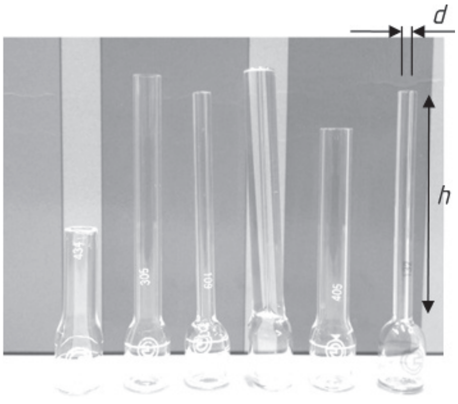
See C.1 and Table C.1.

D.3 Diffusion tube method

A generation of VOC mixture was carried out using as a gas generation system. The gas generation system has a flow meter with needle valve and a thermostatic chamber. VOC solvents, i.e. liquids of *m*-xylene, *n*-octane, toluene, *n*-decane, α-pinene, metyl *i*-butyl ketone, and butyl acetate, were poured into diffusion tubes. Figure D.1 shows the diffusion tubes for the gas generation system. The solid of *p*-dichlorobenzene was also put into the diffusion tube. A diffusion rate, Dr, of VOC depends on an inside diameter and a height of the diffusion tube as well as the temperature. Table D.1 shows basic sizes of the diffusion tube. In a study, the temperature of the thermostatic chamber is almost 50 °C. For controlling the Dr, a part of the diffusion tubes was adjusted. Concentration of each VOC component, φ, is defined in Formula (D.1).

$$\varphi = \frac{Dr \times 10^3}{q_{V,cg}} \qquad (D.1)$$

where $q_{V,\mathrm{cg}}$ is a flow rate of carrier gas into the gas generation system. Table D.2 shows Dr at 50 °C and combination of diffusion tubes for generation of two, four, and six kinds of VOC mixed gases. In the case of six kinds of VOC mixed gas, it was attempted to be generated using two combinations of diffusion tubes for adjusting to the cylinder gas, abbreviated at “test 1” and “test 2”.



Key

h height

d inside diameter

Figure D.1 — Diffusion tubes

Table D.1 — Basic sizes of the diffusion tube

No.	Inside diameter mm	Height mm
D-001	0,8	52
D-01	1,6	50
D-02	2,6	50
D-03	3,9	50
D-04	4,9	40

Table D.2 — List of *Dr* values and combination of diffusion tubes for the generation of two, four, and six kinds of VOC mixed gases

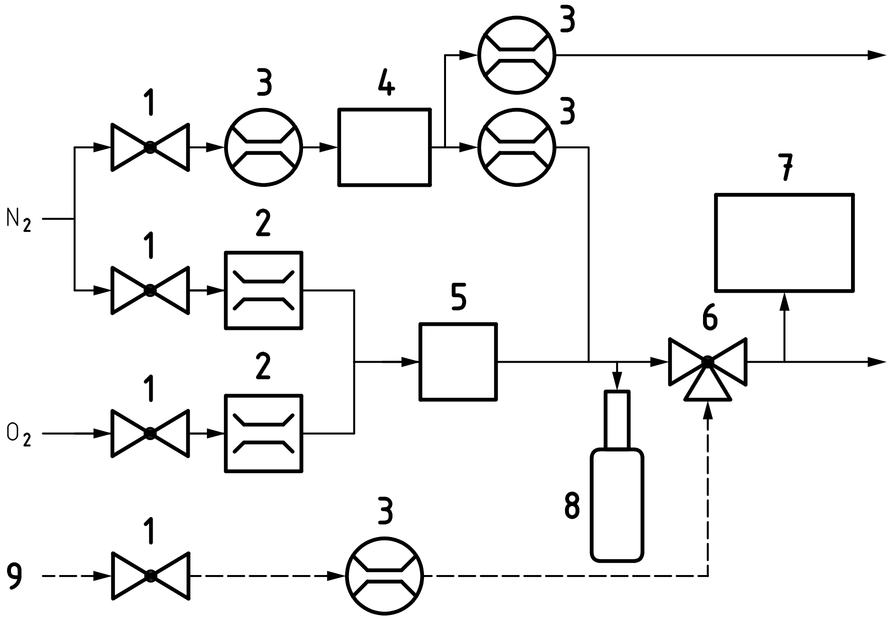
	Diffusion tube	***Dr* at 50 °C** µg/min	***x* kinds of VOC mixed gas**[b]			
			x = 2	*x* = 4	*x* = 6 “test 1”	*x* = 6 “test 2”
m-xylene	D-02 and D-03	28,2	v			
n-octane	D-03	29,9	v			
Toluene	D-001 × 2	5,9			v	
	D-001 and D-01 (25 mm[a])	10,7		v		v
n-decane	D-04 (20 mm[a])	14,0			v	
	D-04 (28 mm[a])	10,8		v		v
α-pinene	D-03	11,1		v	v	v
p-dichlorobenzene	D-04	10,6			v	v
Butyl acetate	D-01 × 2	8,8			v	v
Methyl *i*-butyl ketone	D-01	7,9			v	
	D-01 (45 mm[a])	8,9		v		v

[a] Adjusting the height.

[b] “v” means selection of the diffusion tubes, for example, *x* = 2 (two kinds of VOC mixed gas) uses D-02 and D-03 diffusion tubes for *m*-xylene and D-03 diffusion tube for *n*-octane.

D.4 Measurements

The analyses of the VOC detectors were carried out in a flow apparatus, as shown in Figure D.2. The flow apparatus was equipped with a gas generation system and a water bubbler. A tetrafluoroethylene perfluoroalkylvinylether copolymer (PFA) tube was used as a flow pass of downstream from the gas generation system permeator and a water bubbler. PTFE (polyterafluoroethene) and stainless tubes were used as other flow passes. Mass flow controllers and flow meters with needle valves were used to regulate flow rates of nitrogen and oxygen. The carrier gas of the gas generation system was nitrogen. Part of VOCs mixture gas from the gas generation system was mixed with nitrogen and oxygen mixture gas from the water bubbler. The flow rates of the part of VOCs mixture gas and nitrogen and oxygen mixture gas are to be controlled by adjusting the concentration of VOCs mixture. A thermal controller of the water bubbler was used for maintaining relative humidity at 50 % ± 10 %. The N_2/O_2 ratio was 4 and the total flow rate was 800 ml/min. The GC-MS data were acquired by a GC-MS instrument equipped with a thermal desorption unit. The calibration of the GC-MS was carried out using raw VOC mixed gases from the gas cylinders. The gas sampling rate and time were 60 ml/min and 2 min to 6 min, respectively. The gas sampling was started when the indication value of the portable VOC detectors, which can carry out a real-time monitoring, became stable. The concentration values from the GC-MS were converted into toluene equivalents. The indication values from the portable VOC detectors were recorded at the same time as the GC-MS sampling.



Key

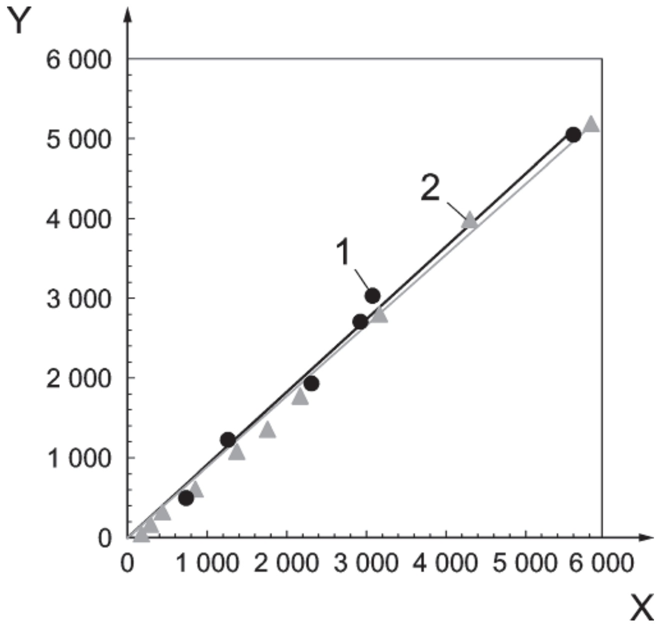
1	valve	6	three ways valve
2	mass flow controller	7	GC-MS
3	flow meter with needle valve	8	portable VOC detector
4	gas generation system	9	VOC gas cylinder
5	water bubbler		

NOTE Dashed flow pass was used for the GC-MS calibration.

Figure D.2 — Schematic diagram of test equipment

D.5 Results of semiconductor detector

Figure D.3 shows the indication values from the semiconductor detector for the two kinds of VOC mixed gas generated by the gas diffusion method. The differences in values obtained from the semiconductor detector for the two kinds of VOC mixed gases generated from the gas cylinder and the gas generation system was so small, 2,7 %, indicating that the diffusion tube method can prepare the calibration gas for the semiconductor detector.



Key

1	diffusion tube
2	gas cylinder
X	GC-MS (toluene equivalent, µg/m^3)
Y	semiconductor detector (µg/m^3)

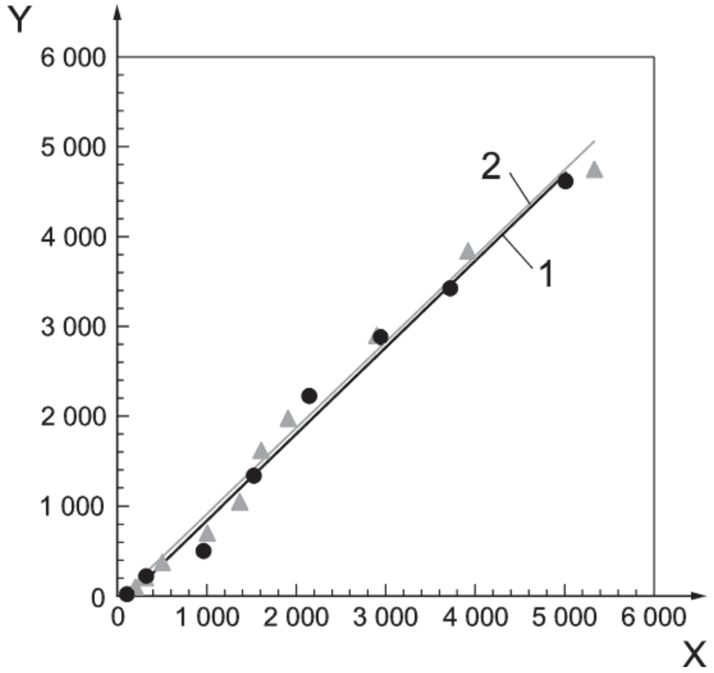
NOTE For comparison, indication values for two kinds of VOC mixed gas generated from gas cylinder are also shown in the figure.

Figure D.3 — Indication values from the semiconductor detector for two kinds of VOC mixed gas generated by the diffusion tube method

D.6 Results of PID

Four and six kinds of VOC mixed gases were found to be the calibration gases for the PID, as shown in Annex C. The cost issue makes the reduced number of mixed gas components attractive for the calibration. The four kinds of VOC mixed gas has adequate reliability for the PID. In this study, the indication values from the PID for four and six kinds of VOC mixed gases generated by the diffusion tube method were evaluated, because of verification of the reliability for the diffusion tube method.

Figure D.4 shows the indication values from the PID for the four kinds of VOC mixed gas. The indication values from the PID correspond to isobutylene equivalents because isobutylene is a standard calibration gas. The difference in values obtained from the PID for the four kinds of VOC mixed gases generated from the gas cylinder and the gas generation system was also so small, −0,30 %. The result should indicate the diffusion tube method was able to prepare the calibration gas for the PID.



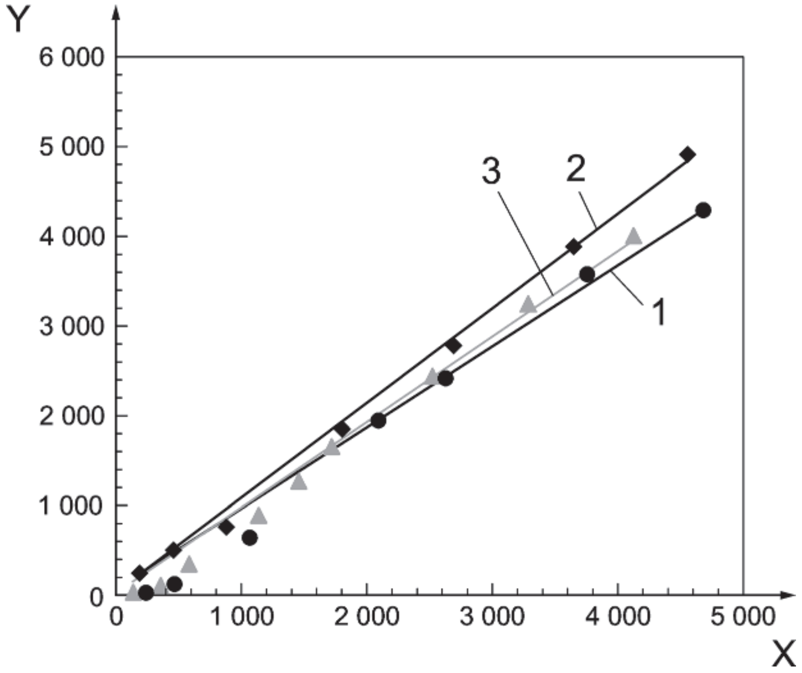
Key

1	diffusion tube
2	gas cylinder
X	GC-MS (toluene equivalent, µg/m^3)
Y	PID (isobutylene equivalent, µg/m^3)

NOTE For comparison, indication values for four kinds of VOC mixed gas generated from gas cylinder are also shown in the figure.

Figure D.4 — Indication values from the PID for four kinds of VOC mixed gas generated by the diffusion tube method

Figure D.5 shows the indication values from the PID for the six kinds of VOC mixed gas. Two types of combinations of diffusion tubes, “test 1” and “test 2”, were used for adjusting to the cylinder gas, as shown in Table D.2. The difference between “test 1” and “test 2” was the height of diffusion tubes, i.e. diffusion rates, for toluene, *n*-decane, and methyl *i*-butyl ketone. Generation amounts of toluene and methyl *i*-butyl ketone in “test 1” are smaller than those in “test 2”, whereas *n*-decane in “test 2” is larger than that in “test 1”. The difference in values obtained from the PID detector for the six kinds of VOC mixed gases generated from the gas cylinder and “test 1” and “test 2” of the diffusion tube were −4,1 % and 10,7 %, respectively. These results would be within the acceptable accuracy of the indication value because of low difference, though the accuracy of the PID detector is not provided by the manufacturer.



Key

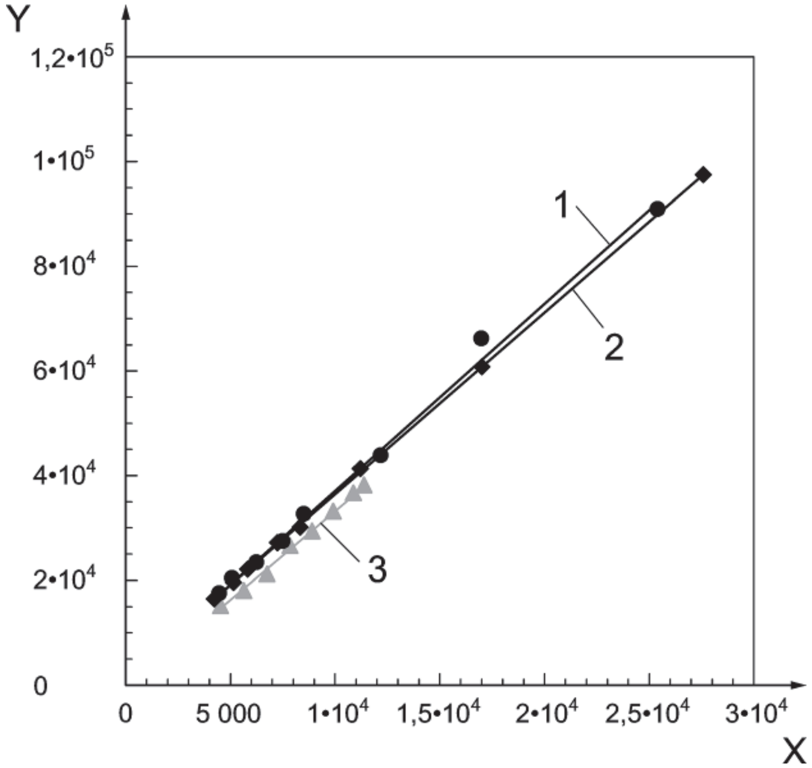
1 diffusion tube “test 1”
2 diffusion tube “test 2”
3 gas cylinder
X PID (isobutylene equivalent, µg/m^3)
Y GC-MS (toluene equivalent, µg/m^3)

NOTE For comparison, indication values for six kinds of VOC mixed gas generated from gas cylinder are also shown in the figure.

Figure D.5 — Indication values from the PID for six kinds of VOC mixed gas generated by diffusion tube method

D.7 Results of IER detector

Figure D.6 shows the indication values from the IER detector for the six kinds of VOC mixed gas generated from the diffusion tube method. The indication values from the IER detector correspond to toluene equivalents because toluene is a standard calibration gas. The difference in values obtained from the IER detector for the six kinds of VOC mixed gases generated from the gas cylinder and “test 1” and “test 2” of the diffusion tube were 9,2 % and 8,3 %, respectively. These results are within the accuracy of the IER detector. The result should indicate the diffusion tube method was able to prepare the calibration gas for the IER detector.



Key

1 diffusion tube “test 1”

2 diffusion tube “test 2”

3 gas cylinder

X GC-MS (toluene equivalent, µg/m^3)

Y IER detector (toluene equivalent, µg/m^3)

NOTE For comparison, indication values for six kinds of VOC mixed gas generated from gas cylinder are also shown in the figure.

Figure D.6 — Indication values from the IER detector for six kinds of VOC mixed gas generated by the diffusion tube method

D.8 Conclusion

The diffusion tube method can provide the calibration gases for the semiconductor, PID, and IER detectors, i.e. two, four, and six kinds of VOC mixed gases.

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