IEC®

IEC 61207-3

Edition 3.0 2019-06
REDLINE VERSION

INTERNATIONAL STANDARD

colour
inside

Gas analyzers – Expression of performance –
Part 3: Paramagnetic oxygen analyzers

IEC 61207-3:2019-06 RLV(en)

IEC Central Office
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
info@iec.ch
www.iec.ch

About the IEC
The International Electrotechnical Commission (IEC) is the leading global organization that prepares and publishes International Standards for all electrical, electronic and related technologies.

About IEC publications
The technical content of IEC publications is kept under constant review by the IEC. Please make sure that you have the latest edition, a corrigendum or an amendment might have been published.

IEC publications search - webstore.iec.ch/advsearchform
The advanced search enables to find IEC publications by a variety of criteria (reference number, text, technical committee,…). It also gives information on projects, replaced and withdrawn publications.

IEC Just Published - webstore.iec.ch/justpublished
Stay up to date on all new IEC publications. Just Published details all new publications released. Available online and once a month by email.

IEC Customer Service Centre - webstore.iec.ch/csc
If you wish to give us your feedback on this publication or need further assistance, please contact the Customer Service Centre: sales@iec.ch.

Electropedia - www.electropedia.org
The world's leading online dictionary on electrotechnology, containing more than 22 000 terminological entries in English and French, with equivalent terms in 16 additional languages. Also known as the International Electrotechnical Vocabulary (IEV) online.

IEC Glossary - std.iec.ch/glossary
67 000 electrotechnical terminology entries in English and French extracted from the Terms and Definitions clause of IEC publications issued since 2002. Some entries have been collected from earlier publications of IEC TC 37, 77, 86 and CISPR.

IEC 61207-3

Edition 3.0 2019-06
REDLINE VERSION

INTERNATIONAL STANDARD

colour
inside

Gas analyzers – Expression of performance –
Part 3: Paramagnetic oxygen analyzers

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 19.040; 71.040.40

ISBN 978-2-8322-7117-9

Warning! Make sure that you obtained this publication from an authorized distributor.

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

GAS ANALYZERS – EXPRESSION OF PERFORMANCE –

Part 3: Paramagnetic oxygen analyzers

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
6) All users should ensure that they have the latest edition of this publication.
7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

This redline version of the official IEC Standard allows the user to identify the changes made to the previous edition. A vertical bar appears in the margin wherever a change has been made. Additions are in green text, deletions are in strikethrough red text.

International Standard IEC 61207-3 has been prepared by sub-committee 65B: Measurement and control devices, of IEC technical committee 65: Industrial-process measurement, control and automation.

This third edition cancels and replaces the second edition published in 2002. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) all references (normative and informative) have been updated, deleted or added to as appropriate;
b) all the terms, descriptions and definitions relating to the document have been updated where appropriate;
c) all references to “errors” have been replaced by “uncertainties” and appropriate updated definitions applied.

The text of this International Standard is based on the following documents:

FDIS	Report on voting
65B/1155/FDIS	65B/1157/RVD

Full information on the voting for the approval of this International Standard can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

This International Standard is to be used in conjunction with IEC 61207-1:2010.

A list of all parts in the IEC 61207 series, published under the general title *Gas analyzers – Expression of performance*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

IMPORTANT – The “colour inside” logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this publication using a colour printer.

INTRODUCTION

Paramagnetic oxygen analyzers respond to the partial pressure of oxygen in the measured gas, and ~~not~~ the volumetric concentration is then determined by knowledge of the total pressure, as in many other gas analyzers. Due to this fact, many paramagnetic oxygen analyzers use pressure compensation (see 4.4.4 and 4.4.5). They are used in a wide range of industrial, laboratory, medical, and other applications where the rated measuring range of the analyzer is between 0 % to 1 % and 0 % to 100 %, at reference pressure (usually near atmospheric).

Only a few gases display significant paramagnetism (for example, oxygen, nitric oxide and nitrogen dioxide), and oxygen has ~~a particularly strong~~ the strongest paramagnetic susceptibility (see Annex A) among gases. By employing this particular property of oxygen, analyzers have been designed that can be highly specific to the measurement in most industrial and medical applications, where, for example, high background levels of hydrocarbons or moisture may be present.

There are several different techniques described for measuring ~~the paramagnetic properties of~~ oxygen by its paramagnetic property, but three main methods have evolved over many years of commercial application.

The three methods are:

- automatic null balance;
- thermomagnetic or magnetic wind;
- differential pressure or Quincke.

These methods all require the sample gas to be clean and ~~dry~~ non-condensing, though some versions work at elevated temperatures so that samples that are likely to condense at a lower temperature can be analyzed. Because of this requirement, analyzers often require a sample system to condition the sample prior to measurement.

GAS ANALYZERS –
EXPRESSION OF PERFORMANCE –

Part 3: Paramagnetic oxygen analyzers

1 Scope ~~and object~~

This part of IEC 61207 applies to the three main methods for measuring oxygen by its paramagnetic property, which are outlined in the introduction. It considers essential ancillary units and applies to analyzers installed indoors and outdoors.

~~NOTE~~ Safety-critical applications can require ~~an~~ additional ~~requirement of~~ requirements from system and analyzer specifications not covered in this document.

This document is intended

- to specify terminology and definitions related to the functional performance of paramagnetic gas analyzers for the measurement of oxygen in a source gas;
- to unify methods used in making and verifying statements on the functional performance of such analyzers;
- to specify what tests ~~should be~~ are performed to determine the functional performance and how such tests ~~should be~~ are carried out;
- to provide basic documents to support the application of internationally recognized quality management standards ~~of quality assurance (ISO 9001, ISO 9002 and ISO 9003)~~.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

~~IEC 60654-1:1993, *Industrial-process measurement and control equipment – Operating conditions – Part 1: Climatic conditions*~~

~~IEC 61115:1992, *Expression of performance of sample handling systems for process analyzers*~~

IEC 61207-1~~:1994~~, *Expression of performance of gas analyzers – Part 1: General*

~~ISO 9001:2000, *Quality management systems – Requirements*~~

~~ISO 9002:1994, *Quality systems – Model for quality assurance in production, installation and servicing*~~

~~ISO 9003:1994, *Quality systems – Model for quality assurance in final inspection and test*~~

3 Terms and definitions

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

NOTE Although cgs (centimetre-gram-second) units have been used in this document, SI (Système International) units (such as defined in IUPAC [1] 1)) can also be used.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1
magnetic susceptibility

measure (X) of the variation of the intensity of a magnetic field H, existing in a vacuum, when the vacuum is substituted (filled) by the test substance, expressed as:

$$X = \frac{H^1 - H}{H}$$

where

H is the magnetic field intensity in vacuum

H^1 is the magnetic field intensity in the test substance

Note 1 to entry: $H^1 - H$ is also known as the magnetisation MV (magnetic dipole per unit volume) and therefore this is also the volume magnetic susceptibility.

3.2
paramagnetism

property of substances causing an increase of the magnetic field intensity ($X > 0$)

3.3
diamagnetism

property of substances causing a diminution of the magnetic field intensity ($X < 0$ because $H^1 < H$)

3.4
specific magnetic susceptibility

ratio of magnetic susceptibility to the density derived as follows:

$$X_s = \frac{X}{D}$$

where

D is the density of the considered substance, expressed in g·cm^{-3} at 273,15 K~~ (0 °C) and~~, 101,3 kPa~~ (= 1 bar).~~

Note 1 to entry: The measuring unit of X_s is therefore cm^3·g^{-1}. This is also known as the mass magnetic susceptibility.

3.5
molar magnetic susceptibility

X_m

specific magnetic susceptibility multiplied by the molecular~~ weight~~ mass (M) of the substance considered:

$$X_m = X_s \cdot M$$

---

[1] Numbers in square brackets refer to the bibliography

where

M is expressed in g per mole (g·mol^{-1}) (for oxygen M = ~~32~~ 31,998 8)

Note 1 to entry: The measuring unit of X_m is therefore cm^3·mol^{-1}.

Note ~~1~~2 to entry: Electrons determine the magnetic properties of matter in two ways:

- an electron can be considered as a small sphere of negative charge spinning on its axis. This spinning charge produces a magnetic moment;
- an electron travelling in an orbit around a nucleus will also produce a magnetic moment.

It is the combination of the spin moment and the orbital moment that governs the resulting magnetic properties of an individual atom or ion.

In paramagnetic materials, the main contribution to the magnetic moment comes from unpaired electrons. It is the configuration of the orbital electrons and their spin orientations that establish the paramagnetism of the oxygen molecule and distinguish it from most other gases.

Note ~~2~~3 to entry: When paramagnetic gases are placed within an external magnetic field, the flux within the gas is higher than it would be in a vacuum, thus paramagnetic gases are attracted to the part of the magnetic field with the strongest magnetic flux. On the contrary, diamagnetic substances contain magnetic dipoles which cancel out some lines of force from the external field; thus diamagnetic gases are subject to repulsion by the magnetic flux.

Note ~~3~~4 to entry: The molar magnetic susceptibility of oxygen is inversely proportional to the absolute temperature~~ T~~. According to Van Vleck [2] the molar susceptibility of oxygen can be approximated by Equation (4).

For oxygen,

$$X_m = \frac{8L \cdot \mu_B^2}{3kT} \tag{4}$$

where

X_m is the molar susceptibility of oxygen, expressed in cm^3·mol^{-1};

L is the Avogadro constant = 6,022 7 × 10^{23} mol^{-1};

μ_B is the Bohr magneton = 9,274 × 10^{-24} A·m^2;

k is the Boltzmann constant = 1,38 × 10^{-23} J·K^{-1};

T is the temperature, expressed in K (kelvin).

Equation (4) can be written as follows:

$$X_m = \frac{1010557}{T} \times 10^{-6}\ \text{cm}^3\cdot\text{mol}^{-1}\ \text{(only for oxygen).}$$

Note 5 to entry: A full understanding of paramagnetism and diamagnetism can be obtained from physics and inorganic chemistry textbooks. The explanation in this document is to give the user of paramagnetic oxygen analyzers a simple understanding of the physical property utilized.

3.6
automatic null balance analyzer

~~this type of~~ analyzer that uses, as a general principle of operation, the displacement of a body containing a vacuum or a diamagnetic gas, from a region of high magnetic field by paramagnetic oxygen molecules

Note 1 to entry: See Figure 1.

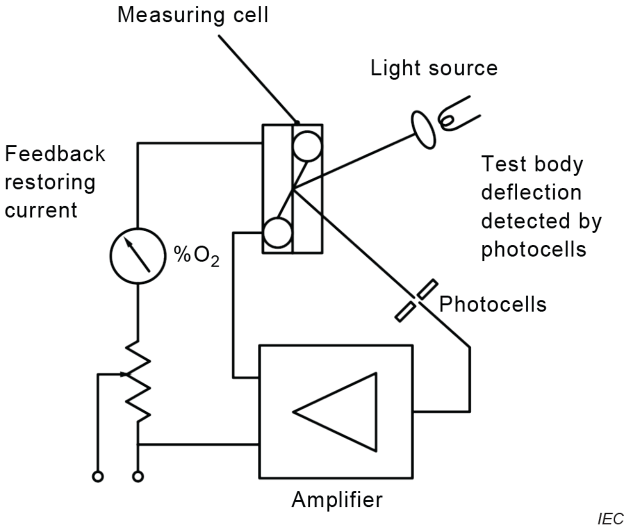


Figure 1 – Magnetic auto-balance system with current feedback

Note 2 to entry: The measuring cell typically employs a glass dumb-bell, with the spheres containing nitrogen, suspended on a torsion strip between magnetic pole pieces or magnets that ~~concentrate the flux~~ produce a very strong magnetic field gradient around the dumb-bell. ~~The measuring cell has to be placed in a magnetic circuit.~~ The dumb-bell is then deflected when oxygen molecules enter the measuring cell, a force being exerted on the dumb-bell by the oxygen molecules which are attracted to the strongest part of the magnetic field. By use of an optical lever~~s~~, a ~~feed-back~~ magnetic actuation coil, and suitable electronics to generate a feedback signal that nulls the magnetic susceptibility force, an output that is directly proportional to the partial pressure of oxygen can be achieved. The transducer ~~is usually~~ can be maintained at a constant temperature to prevent the variations in magnetic susceptibility ~~with~~ to temperature from introducing ~~errors~~ uncertainties. Alternatively, built-in temperature sensors may be used to provide temperature compensation of the oxygen reading. Additionally, the elevated temperature helps in applications where the sample is not particularly dry. Some analyzers are designed so that the transducer operates at a temperature in excess of 373,15 K (100 °C) to further facilitate applications where condensates would form at a lower temperature. Paramagnetic sensor orientation may also affect the oxygen measurement uncertainty and this may be corrected by using a compensation algorithm using, for example, a three-dimensional accelerometer to determine the sensor orientation relative to its orientation during calibration. Due to the mechanical nature of this type of device, there is some inherent susceptibility to vibrational and gyroscopic motion, potentially resulting in increased measurement uncertainty.

3.7
thermomagnetic ~~(magnetic-wind)~~ analyzer

3.7.1
magnetic wind analyzer

~~this type of~~ analyzer ~~utilizes~~ that uses the temperature dependence of the magnetic susceptibility to generate a magnetically induced gas flow which can then be measured by a flow sensor

Note 1 to entry: The sample gas passes into a chamber designed in such a way that the inlet splits the flow.

Note 2 to entry: See Figure 2.

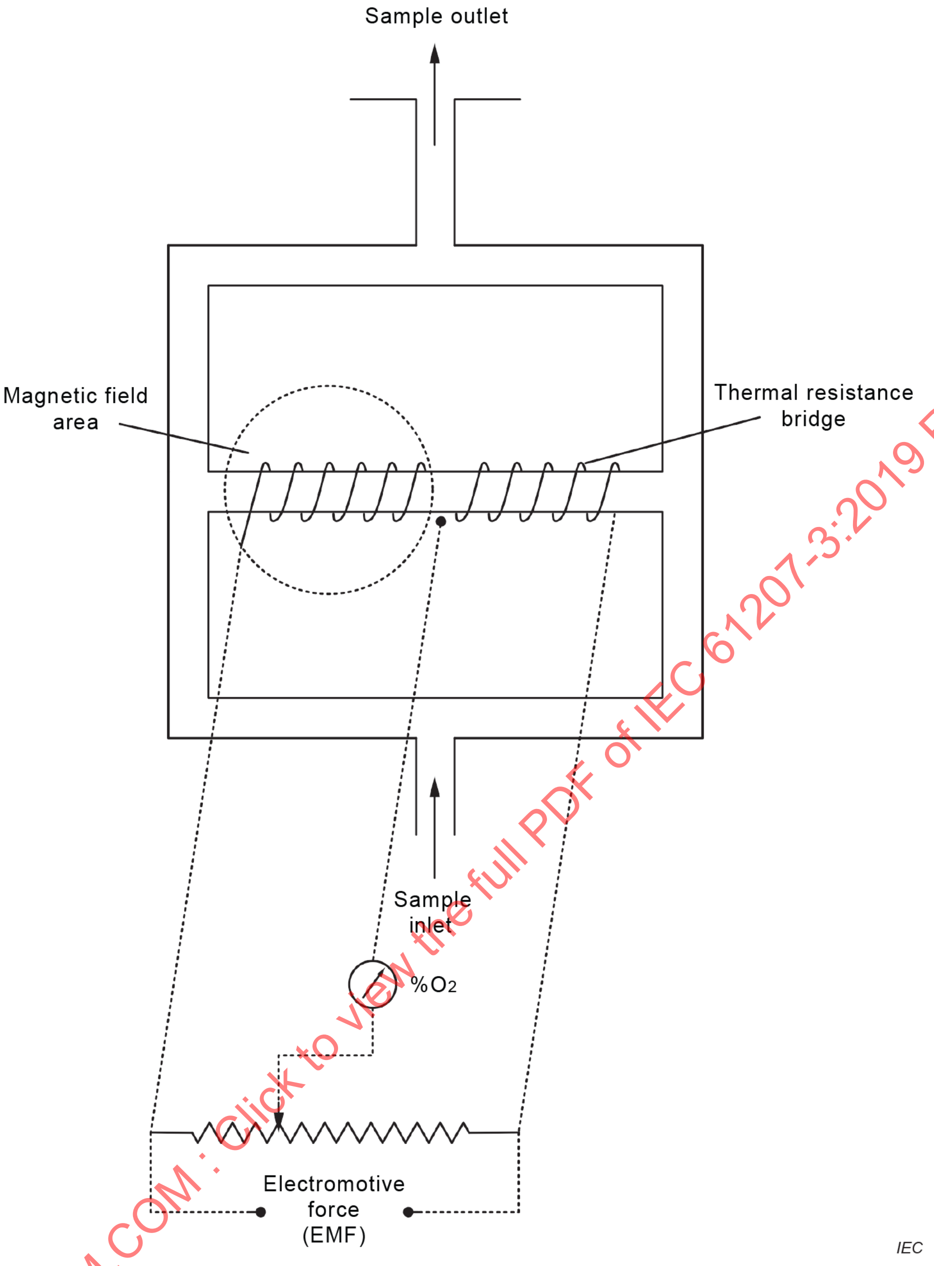


Figure 2 – Thermomagnetic oxygen sensor

Note 3 to entry: The two flows recombine at the outlet. A connecting tube is placed centrally with the flow sensor wound on it. Half of the connecting tube is placed between the poles of a strong magnet. The flow sensor is effectively two coils of wire heated to about 353,15 K (80 °C) by passage of a current. The cold oxygen molecules are diverted by the magnetic field into the central tube, and, as they heat up, their magnetic susceptibility is reduced and more cold oxygen molecules enter the connecting tube. A flow of oxygen is generated in this way through the transversal connecting tube, with the effect of cooling the first coil (which is placed in the magnetic field area), while the temperature of the second coil is not essentially influenced by this transversal flow. Since the two coils are wound with thermosensitive wire (for example, platinum wire) and connected together to build a Wheatstone bridge, the resulting unbalance current is a nearly proportional function of the oxygen partial pressure in the test gas.

More recent analyzers use more refined measuring cells, toroidal shaped resistors instead of the two-coil flow sensor, and employ temperature control to minimize ambient temperature changes.

As this method relies on heat transfer, the thermal conductivity of background gases will affect the oxygen reading and the composition of the background has to be known. Some analyzers can give a first-order correction for this by utilizing further compensation devices.

Thermomagnetic analyzers do not produce a strictly linear output and additional signal processing is required to linearize the output.

3.8
~~differential pressure (~~ Quincke~~)~~ analyzer

3.8.1
differential pressure analyzer

~~this type of~~ analyzer ~~utilizes~~ that uses a pneumatic balance system established by using a flowing reference gas (such as nitrogen or air)

Note 1 to entry: The measuring cell is designed so that at the reference gas inlet the flow is divided into two paths. These flows recombine at the reference gas outlet, where the sample is also introduced. A differential pressure sensor (or microflow sensor) is positioned across the two reference gas flows so that any imbalance is detected. A magnet is situated in the vicinity of the reference gas outlet in one arm of the measuring cell so that oxygen in the sample is attracted into the arm, thereby causing a small back pressure which is detected by the pressure sensor (see Figure 3).

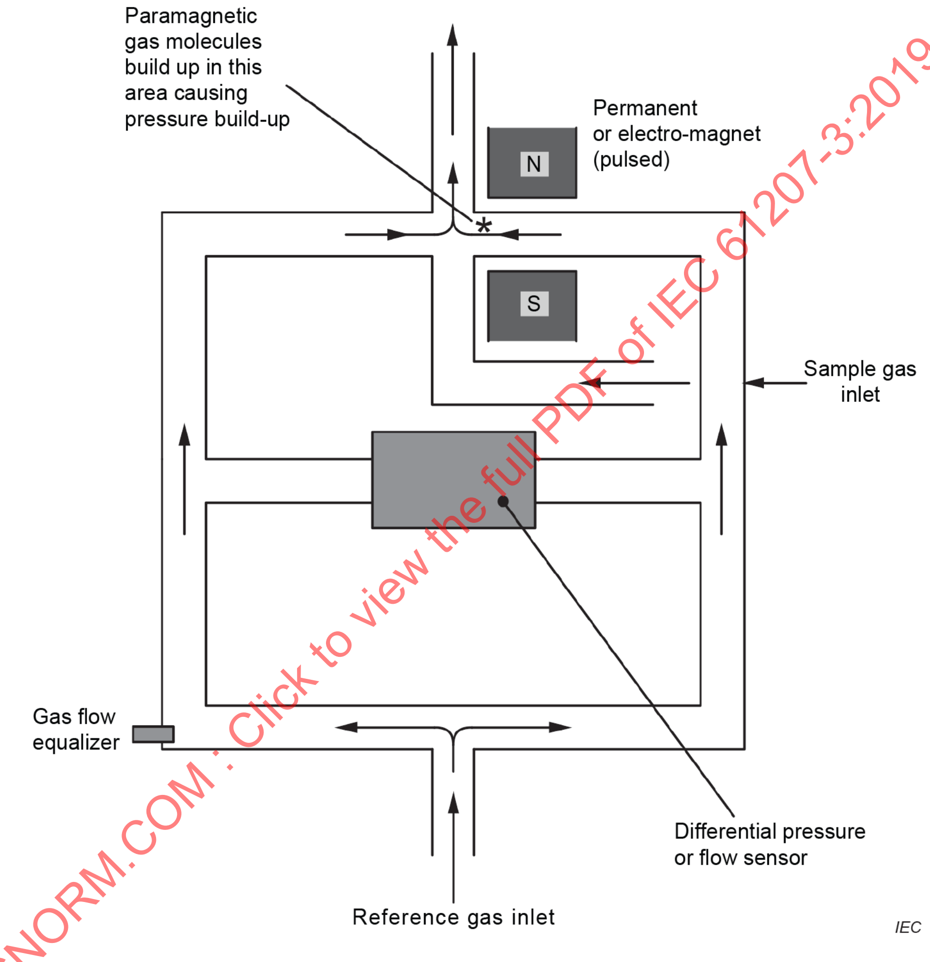


Figure 3 – Differential pressure oxygen sensor

Note 2 to entry: Differential pressure analyzers are independent of thermal conductivity of background gases, and as only the reference gas comes in contact with the sensor, corrosion problems are minimal. Some instruments use pulsed magnetic fields to improve tilt sensitivity, and certain designs compensate for vibration effects.

3.9
hazardous area

~~area where there is a possibility of release of potentially flammable gases, vapours or dusts. Restrictions in the use of electrical equipment apply in hazardous areas~~

area in which an explosive gas atmosphere is present, or may be expected to be present, in quantities such as to require special precautions for the construction, installation and use of devices

3.10
essential ancillary unit

~~essential ancillary units are those~~ unit without which the analyzer will not operate within specifications

EXAMPLE: Calibration systems, reference gas systems, sample systems.

3.11
sample systems

~~see figures 4 and 5 for typical sampling systems. For full details of sample systems requirements, see IEC 61115.~~

~~A sample system is a~~ system of component parts assembled on a panel or in an analyzer house with the purpose of transporting the sample gas from the sampling point to the analyzer and presenting the sample in such a manner that reliable measurements can be obtained

Note 1 to entry: The components used can include

- pressure regulators;
- flow meters;
- flow controllers;
- filtration units;
- pumps;
- valves (manual and/or electrically operated);
- catch or knockout pots;
- coolers;
- heaters;
- drying units;
- scrubbing units.

Note 2 to entry: See Figure 4 and Figure 5 for examples of typical sampling systems. For full details of sample system requirements, see IEC 61115 [3]. These components will usually be designed as a sample system by the user or, more often, by a manufacturer, so that the analyzer requirements defined in the specification are within the rated operating range. The required system design is therefore very dependent on the sample conditions of the process. Variations in sample pressure, temperature, dust loading, and pressure of other gases and vapours will affect the final sample system design.

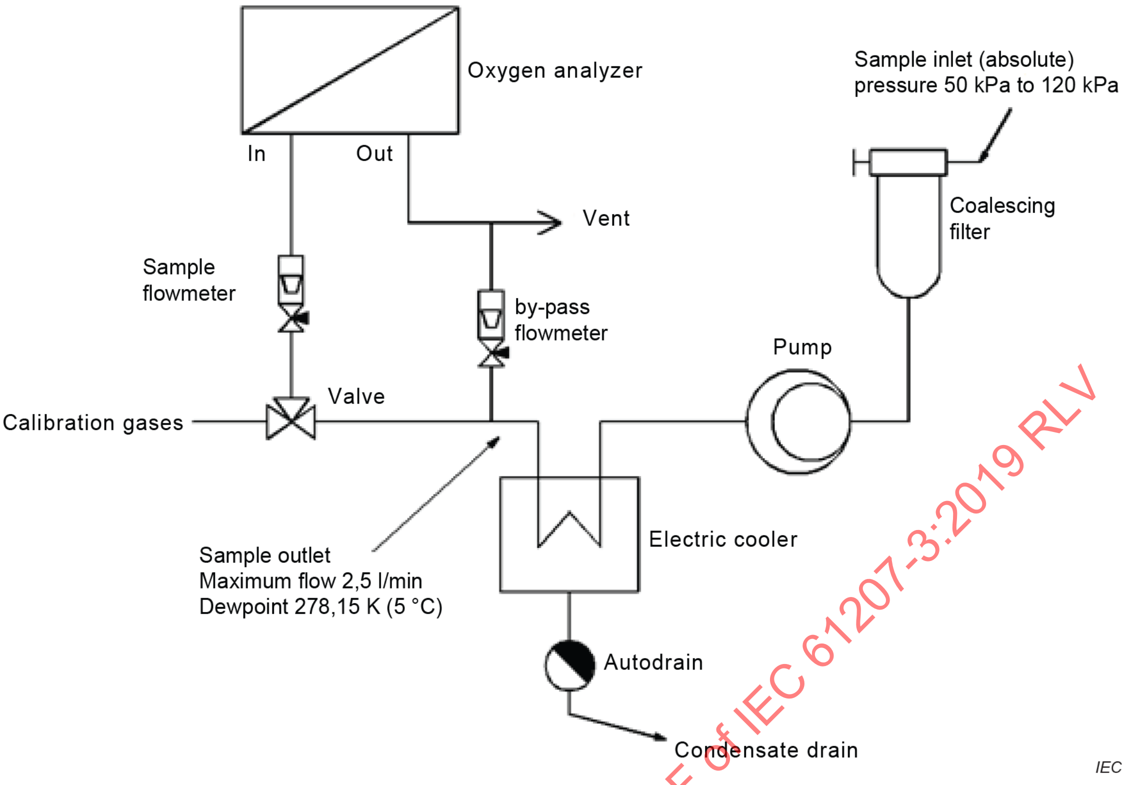


**Figure 4 – Typical sampling systems –
Filtered and dried system with pump for wet samples**

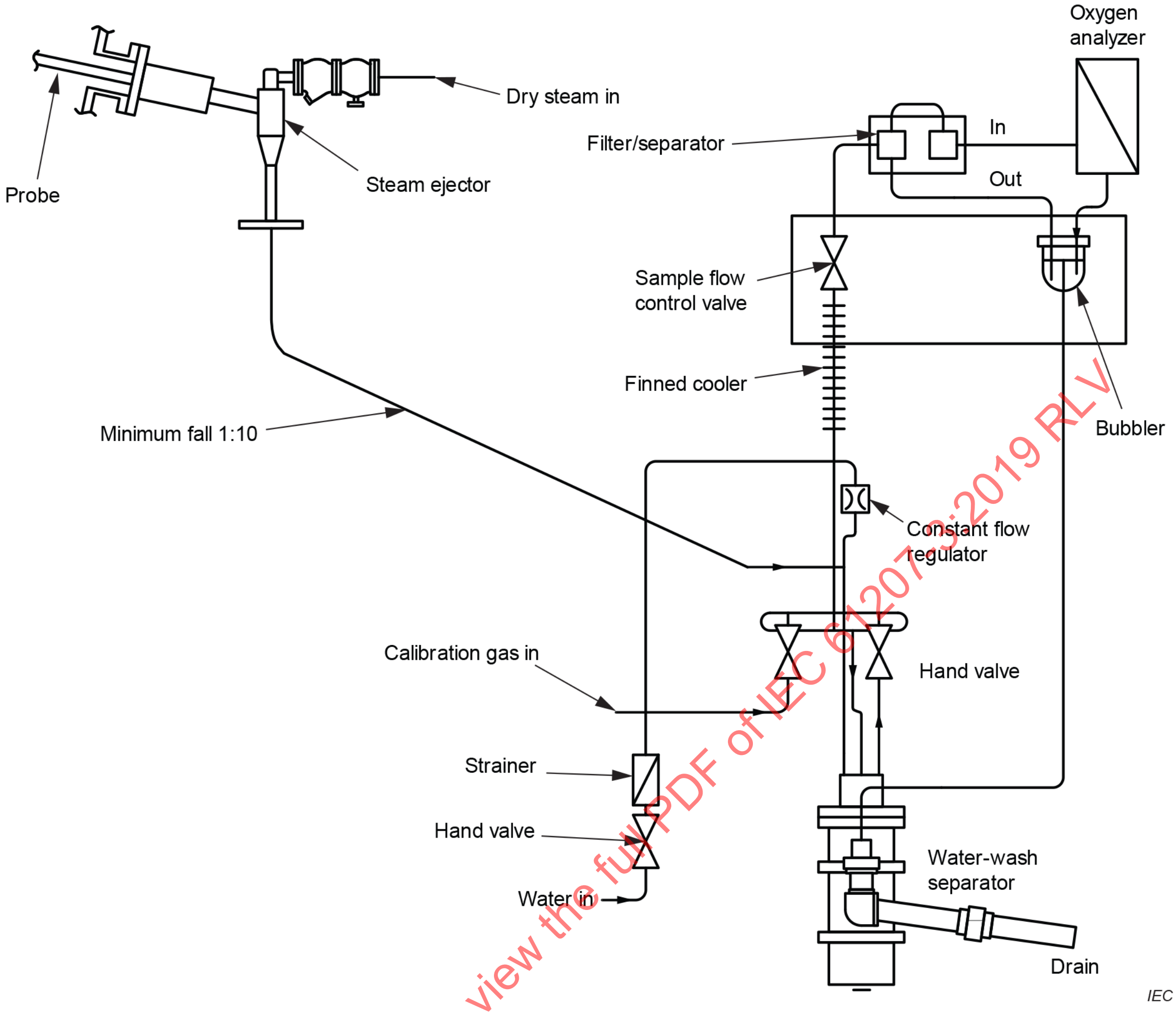


Figure 5 – Typical sampling system – Steam-aspirated system with water wash for wet samples

3.12
sample dew point

dew point of a sample expressed in K and is the temperature at or below which condensation occurs

Note 1 to entry: The analyzer should be operated at a minimum of 5 K above the sample dew point to prevent formation of condensate.

Note 2 to entry: The presence of condensation at the inlet of an analyzer will usually cause malfunction. Condensate may form from water vapour or other vapours depending on the nature of the sample.

3.13
reference gas

~~the Quincke analyzer requires a reference~~ gas of known constant composition

Note 1 to entry: Pure nitrogen is usually employed. The reference gas can have an oxygen content, for example air. This has the effect of giving a suppressed zero and is useful when measuring high oxygen concentrations as it reduces the influence of barometric pressure.

4 Procedures for specification

4.1 General

The procedures are detailed in IEC 61207-1. This covers:

- operation and storage requirements;
- specification of ranges of measurement and output signals;
- limits of ~~errors~~ uncertainties;
- recommended reference values and rated ranges of influence quantities (see IEC 60654-1).

In this part of IEC 61207, requirements for essential ancillary units and services are given. Additional characteristics for specification of performance and important aspects of performance relevant to paramagnetic analyzers are detailed.

4.2 Specification of essential ancillary units and services

4.2.1 Sampling system

The sampling system ~~must~~ shall be specified to supply the sample within the rated range of influence quantities of the analyzer.

NOTE ~~1~~ Simple elements of the sampling system may be included in the analyzer. Sample flow meters, sample flow regulation, bypass flow meters, bypass flow regulations, sample filters are often part of the analyzer.

NOTE ~~2~~ If certain system elements are included in the analyzer the rated range of influence quantities will be less severe compared to an analyzer without any sampling system.

The sampling system will add a delay in addition to the response time of the analyzer. Hence, the sample system response time should be specified.

The chemical composition of the sample stream ~~must~~ shall be considered in the system specification. Special precautions need to be taken for flammable samples, toxic samples or corrosive samples.

Some materials are permeable to oxygen (for example, silicones) and ~~should be avoided~~ the measurement uncertainties that may be introduced by them should be considered and avoided if necessary. For systems measuring very high concentrations of oxygen, the sampling system components should be clean for oxygen service to prevent any dangerous reactions with flammable contaminants.

4.2.2 Services

4.2.2.1 General

Paramagnetic oxygen analyzers will require facilities for calibration after installation. Bottled calibration gases and pressure regulation facilities are generally required. Quincke analyzers will additionally require facilities for supplying the reference gas.

NOTE Nitrogen is usually employed for zero calibration. The span gas will usually be a known concentration of oxygen in nitrogen typically about 80 % of the measuring range. Air contains between 20,64 % and 20,95 % O_2 by volume due to varying humidity. Dry air or instrument air at 20,95 % O_2 can therefore be used for span calibrations. If the oxygen level of the sample gas is high, then 100 % O_2 is usually used as the span gas.

4.2.2.2 Rated range of calibration and reference gas pressure

Calibration and reference gas pressure shall be within the rated range of sample pressure for the analyzer, to prevent possible damage to the paramagnetic sensor.

4.2.2.3 Rated range of calibration and reference gas flow

Calibration and reference gas flow shall be within the rated range of sample flow for the analyzer. For minimum ~~errors~~ uncertainties, the calibration gas flow should be set the same as the sample flow. Excessively high calibration and reference gas flows can damage the paramagnetic sensor, particularly from a large pressure impulse, which may occur if the flow outlet becomes blocked and then quickly released.

4.3 Additional characteristics related to specification of performance

4.3.1 The following additional characteristics to those detailed in IEC 61207-1 may be required to be specified to define the performance of a paramagnetic analyzer or its suitability for a particular application. Depending on the analyzer design details or application, some of these additional terms may be omitted.

4.3.2 Hazardous classification of the area in which the analyzer is to be located. General purpose analyzers will not be suitable for location in hazardous areas.

4.3.3 Flammable gases or vapours should only be sampled by analyzers which are specified as suitable and should be vented from the analyzer in a safe manner.

4.3.4 If the sample gas is toxic, this should be specified, as special maintenance instructions may be required to ensure leak-free operation. Installation of the analyzer ~~must~~ shall also take into account how the sample gas is vented, returned to process, or otherwise dealt with.

4.3.5 The ~~attitude~~ orientation of the analyzer should be considered. In fixed installations, analyzers should be ~~located~~ positioned in an upright ~~attitude~~ manner so that any ~~errors~~ uncertainties due to tilt are minimized. For ~~moving~~ installations that move (for example, ships), the rated range of tilt should be specified.

4.3.6 The vibration sensitivity of the analyzer should be considered. For applications where the vibration levels are outside the rated range of the analyzer, anti-vibration mountings are recommended.

4.3.7 The response time of the analyzer and its sampling system should be considered. The response time specified for the analyzer will usually be considerably less than the sampling system, but is dependent on the sampling system design.

NOTE Some paramagnetic analyzers are designed with adjustable sample flow and bypass flow sample systems.

4.4 Important aspects related to specification of performance

4.4.1 General

Although covered in IEC 61207-1, the following aspects are particularly relevant to paramagnetic analyzers.

4.4.2 Rated range of ambient temperature

The performance of an analyzer is normally ambient temperature-dependent and will have a defined operating range of temperatures within which it will operate within its specification.

4.4.3 Rated range of sample gas temperature

~~NOTE~~ The magnetic susceptibility of oxygen is temperature-dependent, and large ~~errors~~ uncertainties in the measurement value occur unless the analyzer is designed to compensate for the temperature of the sensor. In practice, the temperature of the paramagnetic sensor will depend on ambient temperature and gas temperature. Process paramagnetic oxygen analyzers usually employ temperature-controlled sensors (in addition to temperature compensation) to minimize effects of sample temperature changes and ambient temperature changes. Simple analyzers may not have temperature-controlled sensors, in which case calibration should precede measurements so that ambient temperature effects and sample temperature effects are taken into account.

4.4.4 Rated range of ambient pressure

~~NOTE~~ Measurement values are dependent on sample pressure. If the analyzer is vented to atmosphere, so that the sample within the sensor is at ambient pressure, changes in barometric reading will cause ~~errors~~ uncertainties in the measured value. For analyzers where the measured value is directly proportional to the sample pressure (automatic null balance analyzer), ~~error~~ uncertainty can occur in O_2 readings (% O_2),

$$\Delta O_m = \frac{P_m - P_c}{P_c} \times O_m \qquad (5)$$

where

O_m is the oxygen reading at time of measurement in % O_2;

P_m is the absolute ambient pressure at time of measurement in kPa;

P_c is the absolute ambient pressure at time of calibration in kPa.

Barometric pressure compensation is usually offered by manufacturers to minimize this type of ~~error~~ uncertainty.

4.4.5 Rated range of sample pressure

If the sample is returned to the process stream (assuming process pressure is within the rated range of sample pressure), variations in process pressure will cause similar ~~errors~~ uncertainties to those described in 4.4.4.

Sample pressure compensation is usually offered by manufacturers of process analyzers so that this type of ~~error~~ uncertainty is minimized.

4.4.6 Rated range of sample flow

~~Errors~~ Uncertainties in indicated value due to sample flow can be minimized by setting the calibration flow rates to the expected sample flow rates.

4.4.7 Rated range of sample dew point

Samples ~~must~~ shall be supplied within the rated range of the sample dew point to increase performance reliability. Also, differences in indicated value will occur if the measurement is made on a wet basis compared to a dry basis.

NOTE 1 If the rated range of sample dew point for an analyzer is low, then the sampling system ~~may~~ can have to remove water vapour from the sample. If, for example, 10 % water vapour were removed by the sample system, the corresponding indicated oxygen value would be 100/90 times greater than the value in the wet sample.

NOTE 2 Some oxygen analyzers are designed so that the sensor is controlled at temperatures within the range 333,15 K to 393,15 K (60 °C to 120 °C). This will enable relatively wet samples to be analyzed reliably. For example, a sample saturated with water vapour at 294,15 K (21 °C) contains approximately 2,5 % water vapour. This wet sample would normally be within the rated range of the sample dew point for an analyzer wherein the sensor is controlled at 333,15 K (60 °C). However, the water content in the sample will produce a volumetric error compared to a measurement made on a dry basis where the water has been removed prior to measurement.

4.4.8 Rated range of sample particulate content

Paramagnetic oxygen analyzers usually require a relatively clean sample to ensure reliable operation. The rated range of particulates defined in mass per cubic metre (mg/m^3), and maximum particulate size in microns (µm) should not be exceeded.

4.4.9 Rated range of interference ~~errors~~ uncertainties

~~NOTE~~ Paramagnetic oxygen analyzers are by design specifically measuring the magnetism of the sample gas. Oxygen has a high magnetic susceptibility and the measurement is therefore quite specific, but see Annex A for interferences of other common gases. Nitrogen oxide, in particular, has a significant cross-interference.

Some oxygen analyzers will have interference ~~errors~~ uncertainties from properties of gases other than the magnetic susceptibility. For example, gases of high thermal conductivity in the sample may introduce ~~errors~~ uncertainties in the indicated value in magnetic wind analyzers, though modern analyzers may partially compensate for this.

Water vapour content shall be in the rated range of the sample dew point (see 4.4.7). Interference ~~errors~~ uncertainties, other than those due to volumetric effects, may occur.

4.4.10 Rated range of linearity ~~error~~ uncertainty

Some analyzers are inherently linear and have very small linearity ~~errors~~ uncertainties.

4.4.11 Rated ranges of influence quantities

Ranges for climatic conditions, mechanical conditions and main supply conditions are specified in IEC 60654-1.

NOTE In addition, paramagnetic oxygen analyzers ~~may~~ can be affected by the presence of nearby magnetic ~~material~~ fields.

5 Procedures for compliance testing

5.1 ~~Introduction~~ Analyzer testing

5.1.1 General

The tests considered in Clause 5 apply to the complete analyzer as supplied by the manufacturer and include all essential ancillary equipment. The analyzer will be set up by the manufacturer, or in accordance with his instruction, prior to testing.

5.1.2 Test equipment

The following test equipment for verification of values that confirm the performance of paramagnetic oxygen analyzers will be required.

a) Gas mixing equipment to prepare the required test gases (certified calibration gases can be used).

b) Equipment to present the test gases to the analyzer at the required pressure, flow and temperature. Gases have to be switched over to enable response time measurements.

c) Equipment to measure interference ~~errors~~ uncertainties. This will also include temperature controlled bubblers or other moisture generation equipment so that the effects of water vapour can be measured.

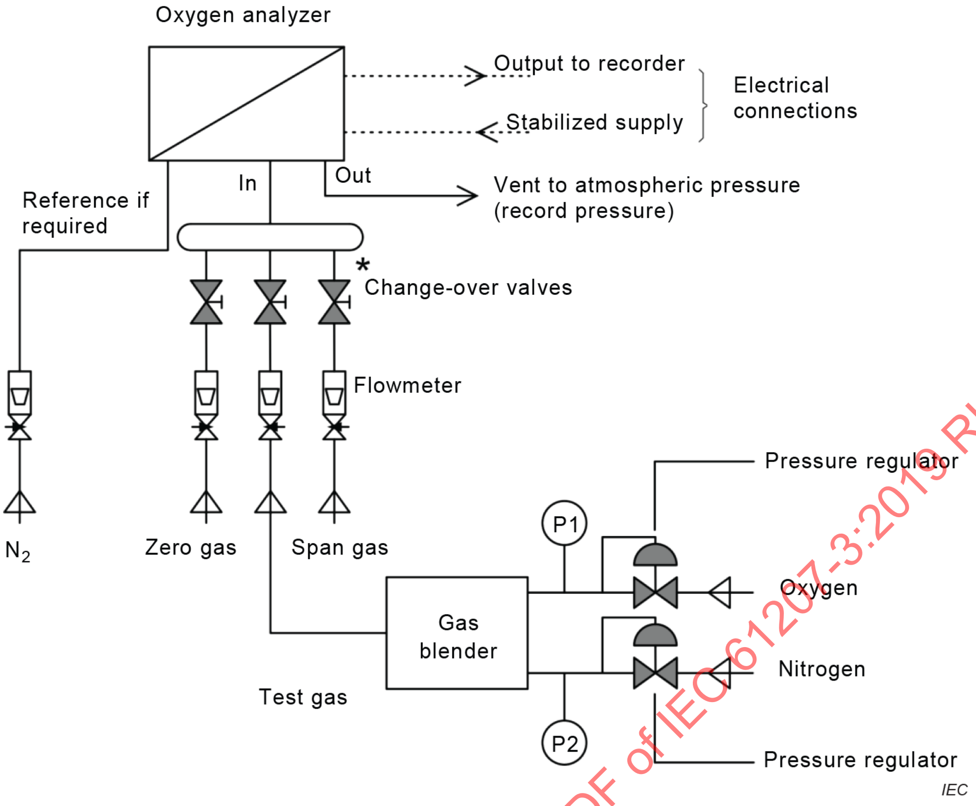
d) An environmental chamber will be required to measure appropriate influence ~~errors~~ uncertainties, such as temperature or humidity.

e) Equipment for determining influence quantities from variation in supply voltage, frequency and supply interruption.

f) Equipment to determine influence ~~errors~~ uncertainties due to electromagnetic susceptibility. Radiated emissions may have to be determined.

g) Equipment to determine influence ~~errors~~ uncertainties under vibration.

Figure 6 shows the general test arrangement for dry gases.



* Dead space to be minimized to avoid uncertainties in response time measurement.

Figure 6 – General test arrangement – Dry gases

5.2 Testing procedures

5.2.1 General

The following relevant testing procedures are detailed in IEC 61207-1.

- Intrinsic ~~error~~ uncertainty.
- Linearity ~~error~~ uncertainty.
- Repeatability ~~error~~ uncertainty.
- Output fluctuation.
- Drift.
- Delay time, rise time, fall time.
- Warm-up time.
- Variations (influence ~~errors~~ uncertainties).
- Interference ~~errors~~ uncertainties.

Any ancillary equipment for the correct functioning of the analyzer will be kept under reference conditions.

Additional test details required for paramagnetic oxygen analyzers are given below.

5.2.2 Interference ~~error~~ uncertainty

The value for testing and the statement of interference ~~errors~~ uncertainties shall be agreed between the manufacturer and user prior to testing.

The manufacturer bears an obligation to indicate components (and their concentrations) and parameters which are expected, from experience, to provide interference equal to, or greater than, the minimum detectable concentration. This will include sample pressure if pressure compensation is not provided.

Interference ~~errors~~ uncertainties are determined by first presenting the analyzer with the calibration gas and then sequentially with gases that contain the highest expected concentration of interfering components, and then at half that level, and which are otherwise identical to the calibration gas.

Zero calibration gas may be used where the interference ~~error~~ uncertainty is not expected to vary significantly through the effective range.

Each test is repeated three times, and the average ~~errors~~ uncertainties are determined and recorded in terms of the equivalent concentration of the component to be determined.

5.2.3 Wet samples

If it is required that tests are performed on the rated range of the dew point, or to measure interference ~~errors~~ uncertainties due to water vapour, the following is relevant.

Water vapour interference, after allowance for dilution, can be determined by the same procedure as stated in 5.2.2. However, the method of preparation of gases with a known concentration of water vapour requires special equipment such as shown in Figure 7 or by using another suitable system. Examples of calculations of water vapour content using the equipment of Figure 7 are shown in Annex B.

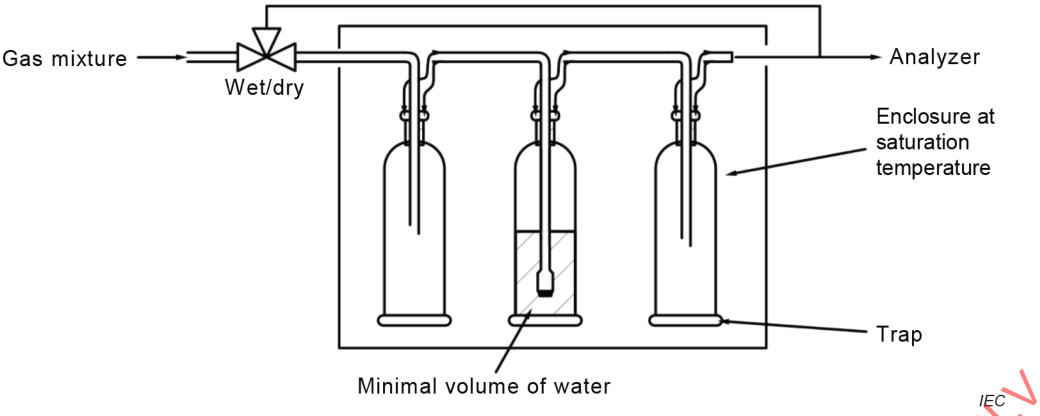
All pipework from the point of water vapour or other condensable vapour addition, up to the analyzer sample inlet, ~~must~~ shall be maintained above the dew point.

The reference conditions will be with dry test gases.

For analyzers requiring testing at high dew points, the bubbler and sample pipework and cell may be operated at elevated temperatures. The partial pressure for water vapour may be calculated over the range 273,15 K to 373,15 K (0 °C to 100 °C) as in Equation (B.1).

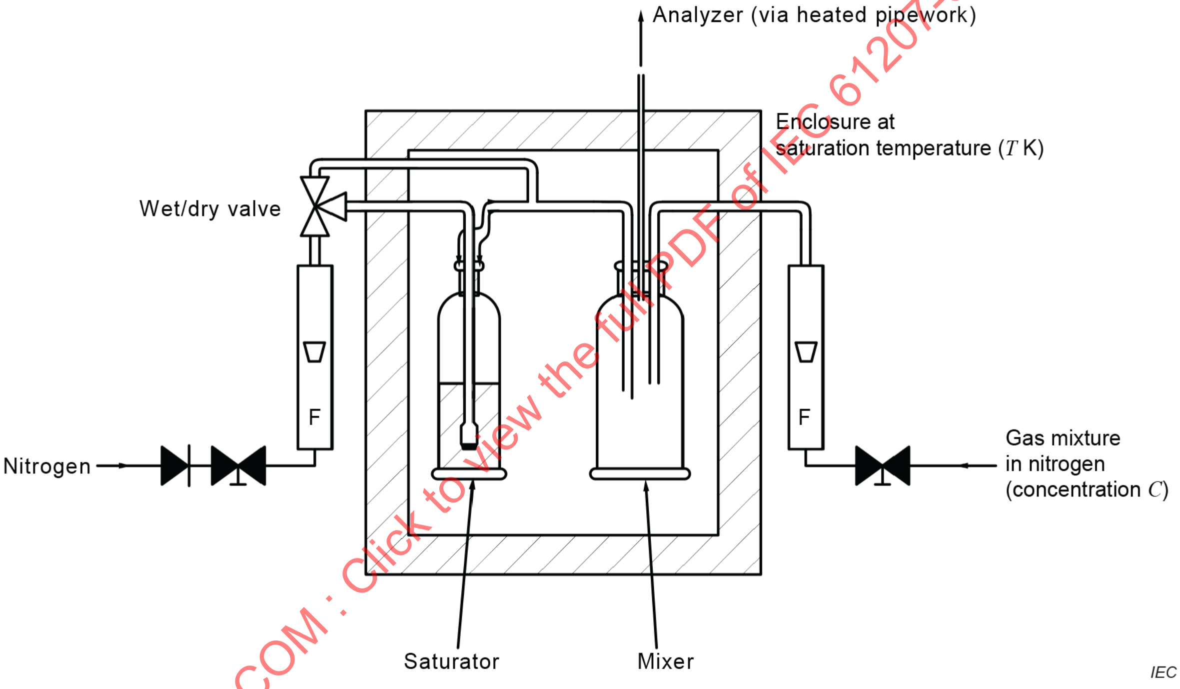
5.2.4 Delay times, rise time, fall time

In determining these response times, it is important to consider the effects of the sample pipe and components as the stated values will be specified at the sample inlet of the analyzer. Also, stated response values will usually require that sample flow rate is at the maximum within its rated range~~, similarly with~~ and the same applies to the bypass flow if this function is fitted to the analyzer.



Enclose trap only for temperatures below 273 K. Long equilibration times will be required. All gas mixture components shall be insoluble.

a) Simple bubbler to apply water vapour to sampling systems



Pipework/components to be in stainless steel, glass, PTFE.

b) Apparatus to apply water vapour at high concentrations or to avoid long equilibration times

Figure 7 – Test apparatus to apply gases and water vapour to analysis systems

Annex A
(informative)

Interfering gases

Oxygen is a paramagnetic gas, i.e. it is attracted into a magnetic field. Virtually all other gases are diamagnetic, i.e. repelled from a magnetic field. Paramagnetic oxygen analyzers are usually calibrated on a scale which is normalized for nitrogen at 0 and oxygen at 100. For highly accurate measurements, it may be necessary to introduce a zero offset into the calibration to compensate for the background gas. Table A.1 gives the correction factors for many common gases. Some values given are calculated, others measured, and as such, should be considered as indicative rather than absolute values.

Example 1: an analyzer calibrated with nitrogen as the zero gas and oxygen as the span gas will, when 100 % carbon dioxide is passed through it, show a reading of −0,30 % O_2. If the purpose is to measure oxygen in carbon dioxide then this will give an ~~error~~ uncertainty. There are two ways to compensate for this.

a) Carbon dioxide is used as the zero gas.

b) Nitrogen is used as the zero gas, but the zero is set to an offset equal but opposite to the background gas (i.e. +0,30 % O_2).

Example 2: if the background gas is a mixture, then the proportional sum of the zero ~~errors~~ uncertainties is used to calculate the zero offset. Assuming N_2 is used as the zero gas, and that the background gas ~~with a composition~~ is composed of 12 % CO_2, 5 % CO, 5 % n-Octane, 78 % N_2, the zero offset will be:

12 % CO_2	=	12 % of −0,30	=	−0,04
5 % CO	=	5 % of +0,07	=	+0,00
5 % n-Octane	=	5 % of −2,78	=	−0,14
78 % N_2	=	78 % of 0,00	=	+0,00
Total:	=	−0,18		

In this case, zero offset would be set at +0,18.

Alternatively, as in Example 1, the actual background gas could be used as the zero gas.

NOTE 1 Nitrogen dioxide exists in equilibrium with dinitrogen tetroxide. The relative proportions vary greatly with temperature between 253,15 K (−20 °C) and 403,15 K (130 °C). As nitrogen dioxide is paramagnetic and dinitrogen tetroxide is diamagnetic, the relative molar susceptibility of the equilibrium gas also varies. The value of the molar magnetic susceptibility of nitrogen dioxide in Table A.1 is at 408,15 K (135 °C). The zero ~~error~~ uncertainty at 333,15 K (60 °C) is estimated and depends considerably on the equilibrium ratio of nitrogen dioxide and dinitrogen tetroxide at 333,15 K (60 °C).

NOTE 2 In Table A.1, the zero ~~error~~ uncertainty assumes 100 % by volume of interference gas as it is at 333,15 K (60 °C). Data for other temperatures ~~may be~~ is available from some instrument manufacturers and for other gases not listed.

The molar magnetic susceptibility is largely independent of temperature for diamagnetic substances and is negative. Only three gases in Table A.1 are paramagnetic, having a positive molar molecular susceptibility. These are oxygen, nitrogen dioxide and nitric oxide. In these cases, the value of molar magnetic susceptibility is dependent on temperature (for example see Equation (4) for oxygen), and the values are given for 293,15 K (20 °C) apart from nitrogen dioxide (408,15 K (135 °C)). (See Note 1 above.)

Table A.1 – Zero correction factors for current gases

Gas	Formula	Molar magnetic susceptibility $\times 10^{-6}$ $cm^3.mol^{-1}$	Zero error at 60 °C
Acetaldehyde	CH_3CHO	−22,70	−0,35
Acetic acid	CH_3CO_2H	−31,50	−0,64
Acetone	CH_3COCH_3	−33,70	−0,71
Acetylene	$HCCH$	−20,80	−0,29
Acrylonitrile	$CH_2 = CHCN$	−24,10	−0,40
Ammonia	NH_3	−18,00	−0,20
Argon	Ar	−19,60	−0,25
Benzene	C_6H_6	−54,84	−1,41
Boron chloride	BCl_3	−59,90	−1,57
Bromine	Br_2	−73,50	−2,02
n-Butane	C_4H_{10}	−50,30	−1,26
Isobutane	$(CH_3)_2CHCH_2$	−51,70	−1,30
Butene-1 (ethylacetylene)	$CH_3CH_2CH = CH_2$	−41,10	−0,96
Iso-Butylene	$(CH_3)_2CH = CH_2$	−44,40	−1,06
Butyne-1	$CH_3C_3H_2$	−43,50	−1,03
Carbon dioxide	CO_2	−21,00	−0,30
Carbon disulfide	CS_2	−42,20	−0,99
Carbon monoxide	CO	−9,80	0,07
Carbon tetrachloride	CCl_4	−66,60	−1,79
Carbon tetrafluoride	CF_4	−31,20	−0,63
Chlorine	Cl_2	−40,50	−0,94
Chloroform	$CHCl_3$	−59,30	−1,55
Cyclohexane	C_6H_{12}	−68,13	−1,84
Cyclopentane	C_5H_{10}	−59,18	−1,55
Cyclopropane	C_3H_6	−39,90	−0,92
Cumene	$(CH_3)_2CHC_6H_5$	−89,53	−2,55
Diacetylene	C_4H_2	−37,50	−0,84
Dichloroethylene	$(CHCl)_2$	−49,20	−1,22
2,2-Difluoro-1-chloroethane	$CClH_2\text{-}CHF_2$	−52,40	−1,33
1,2-Difluoro-1,2-dichloroethylene	$CFCl = CFCl$	−60,00	−1,58
Difluoro-dichloro-methane (Freon 12)	CCl_2F_2	−52,20	−1,32
Dimethoxy methane	$CH_2(OCH_3)_2$	−47,30	−1,16
Dimethylamine	$(CH_3)_2NH$	−39,90	−0,92
Dimethylether	CH_3OCH_3	−26,30	−0,47
Dimethylethylamine	$(CH_3)_2NC_2H_5$	−63,60	−1,69
Ethane	CH_3CH_3	−26,80	−0,49
Ethanol	CH_3CH_2OH	−33,60	−0,71
Ethylamine	$C_2H_5NH_2$	−39,90	−0,92
Ethylbenzene	$C_6H_5CH_2CH_3$	−77,20	−2,14
Ethylbromide	CH_3CH_2Br	−54,70	−1,40
Ethylchloride	CH_3CH_2Cl	−46,00	−1,12

Gas	Formula	Molar magnetic susceptibility × 10^{-6} $cm^3.mol^{-1}$	Zero error at 60 °C
Ethylene	CH_2CH_2	−18,80	−0,22
Ethylene glycol	CH_2OHCH_2OH	−38,80	−0,88
Ethylene oxide	$(CH_2)_2O$	−30,70	−0,61
Ethylmercaptan	$C_2H_5OSO_3H$	−47,00	−1,15
Fluorochlorobromo-methane	CFClBrH	−58,00	−1,51
Fluorodichloro-methane (Freon 21)	Cl_2CHF	−48,80	−1,21
Furan	C_4H_4O	−43,09	−1,02
Halothane	$C_2HBrClF_3$	−78,80	−2,19
Helium	He	−1,88	0,33
n-heptane	$CH_3(CH_2)_3CH_3$	−85,24	−2,40
n-hexane	$CH_3(CH_2)_3CH_4$	−73,60	−2,02
Hydrogen	H_2	−3,98	0,26
Hydrogen Bromide	HBr	−35,30	−0,76
Hydrogen Chloride	HCl	−22,60	−0,35
Hydrogen iodide	HI	−48,20	−1,19
Hydrogen selenide	H_2Se	−39,20	−0,89
Hydrogen sulphide	H_2S	−25,50	−0,44
Isoprene	C_5H_8	−44,80	−1,08
Isopropanol	$(CH_3)_2CHOH$	−47,60	−1,17
Ketene	CH_2CO	−15,70	−0,12
Krypton	Kr	−28,80	−0,55
Methane	CH_4	−17,40	−0,18
Methyl acetate	CH_3COCH_3	−42,60	−1,00
Methanol	CH_3OH	−21,40	−0,31
Methyl cyclopentane	C_6H_{12}	−70,20	−1,91
Methylene chloride	CH_2Cl_2	−46,60	−1,14
Methylethyl ketone	$CH_3COCH_2CH_3$	−45,50	−1,10
Methyl fluoride	CH_3F	−25,50	−0,44
Methyl formate	$HCOOCH_3$	−32,00	−0,66
Methyl iodide	CH_3I	−57,20	−1,48
Methyl iso-butyl ketone (MIBK)	$C_4H_9COCH_3$	−69,30	−1,88
Methyl mercaptane	CH_3SH	−35,30	−0,76
Molybdenum hexafluoride	MoF_6	−26,00	−0,46
Neon	Ne	−6,70	0,17
Nitric oxide	NO	1 461,00	42,94
Nitrous oxide	N_2O	−18,90	−0,23
Nitrogen	N_2	−12,00	0,00
Nitrogen dioxide	NO_2	150,00	20,00
n-Nonane	C_9H_{20}	−108,13	−3,16
n-Octane	C_8H_{18}	−96,63	−2,78
Oxygen	O_2	3 449,00	100,00
n-Pentane	C_5H_{12}	−63,10	−1,68

Gas	**Formula**	**Molar magnetic susceptibility × 10^{-6} $cm^3.mol^{-1}$**	**Zero error at 60 °C**
Phenol	C_6H_5OH	−60,21	−1,58
Phosphine	PH_3	−26,00	−0,46
Propane	C_3H_8	−38,60	−0,87
Propene	$CH_3CH = CH_2$	−31,50	−0,64
Propylamine	$C_3H_7NH_2$	−52,40	−1,33
Propyl chloride	C_3H_7Cl	−56,10	−1,45
Propylene	C_3H_6	−31,50	−0,64
Propylene oxide	OCH_2CHCH_3	−42,50	−1,00
Propyl fluoride	C_3H_7F	−52,20	−1,32
Silane	SiH_4	−20,50	−0,28
Styrene	$C_6H_5CH = CH_2$	−68,20	−1,85
Sulphur dioxide	SO_2	−18,20	−0,20
Sulphur hexafluoride	SF_6	−44,00	−1,05
Tetrachloroethylene	$Cl_2C = CCl_2$	−81,60	−2,28
Tetrahydrofuran	C_4H_8O	−52,00	−1,31
Toluene	$C_6H_5CH_3$	−66,11	−1,78
Trichloro-ethylene	$CHCl = CCl_2$	−65,80	−1,77
Trifluoro-chloro-ethylene	C_2F_3Cl	−49,10	−1,22
1,1,2-Trichloro-ethane (Freon 113)	$CHCl_2\text{-}CH_2Cl$	−66,20	−1,78
Trimethylamine	$(CH_3)_3N$	−51,70	−1,30
Tungstenfluoride	WF_6	−40,00	−0,92
Urethane	$CO(NH_2)OC_2H_5$	−57,00	−1,48
Vinyl bromide	$CH_2 = CHBr$	−44,80	−1,08
Vinyl chloride	$CH_2 = CHCl$	−35,60	−0,77
Vinyl fluoride	$CH_2 = CHF$	−28,80	−0,55
Water	H_2O	−13,00	−0,03
Xenon	Xe	−43,90	−1,05
Xylene	$(CH_3)_2C_6H_4$	−77,78	−2,16
Molar magnetic susceptibility values in Table A.1 should be considered as indicative rather than absolute values.			

Annex B
(informative)

Methods of preparation of water vapour in test gases

For water vapour:

$$\text{Partial pressure} = \text{Antilog}_{10} \frac{(t-280{,}1066)}{33{,}449+0{,}13907(t-280{,}1066)} \text{ kPa} \tag{B.1}$$

where

t is the dewpoint temperature, in K.

For mixing dry gases and water vapour in pipework above 373,15 K (100 °C), see Figure 7.

$$C_{\text{water}} = \frac{0{,}455\,MT}{(f+0{,}00455\,MT)}$$

$$C_x = \frac{C1_x}{100}\left(100 - C_{\text{water}}\right)$$

where

C_{water}	is the concentration of water vapour in the final gas mixture, in per cent at 101,3 kPa;
$C1_x$	is the concentration of component x in the dry gas prior to ~~mixture~~ mixing with water, in any units;
C_x	is the concentration x in the final gas mixture, in the same units as $C1_x$;
M	is the rate of addition of liquid water, in ~~kilograms~~ grams per unit time;
f	is the flow rate of dry gas to the mixing point, in ~~dm³~~ cm^3 per unit time;
T	is the measurement temperature to which f refers, in K.

Example for Figure 7a).

The solubility of acidic gases is much reduced if the pH of the water is reduced to below 2 by the addition of sulphuric acid. The effect on vapour pressure in the range 0,01 to 0,1 molar sulphuric acid is less than 1 %.

At saturation temperature = 288,15 K (15 °C) from Equation (B.1), the partial pressure of water vapour is:

$$\text{Antilog}_{10} \frac{(288{,}15-280{,}1066)}{33{,}449+0{,}13907(288{,}15-280{,}1066)} \text{ kPa} = 1{,}71 \text{ kPa}$$

For gas passing through the bubbler at a pressure of 101,3 kPa:

$$\text{Concentration} = \frac{1{,}71}{101{,}3} \times 100 = 1{,}69\ \%$$

Dilution ratio = 1 − 0,016 9 = 0,983

Example for Figure 7b).

At saturation temperature = 333,15 K (60 °C), partial pressure of water vapour from Equation (B.1) is 19,9 kPa.

For a dry flow of ~~0,45 dm³~~ 450 $cm^3 \cdot min^{-1}$ and a gas flow into the bubbler of ~~0,05 dm³~~ 50 $cm^3 \cdot min^{-1}$, this latter flow expands under constant pressure because of the contribution from water vapour to the total pressure:

Final gas volume flow =

~~$0,05 \times \frac{101,3}{(101,3\ -\ 19,9)} + 0,45\ dm^3 \cdot min^{-1} = 0,512\ dm^3 \cdot min^{-1}$~~

$$50 \times \frac{101,3}{(101,3\ -\ 19,9)} + 450\ cm^3 \cdot min^{-1} = 512\ cm^3 \cdot min^{-1}$$

Dilution ratio =

~~$\frac{0,45}{0,512} = 0,879$~~

$$\frac{450}{512} = 0,879$$

Partial pressure of water vapour in gas mixture

~~$= \frac{19,9 \times 0,05\,(101,3/(101,3 - 19,5))}{0,512} = 2,42\ kPa$~~

$$= \frac{19,9 \times 50\left(101,3/\left(101,3 - 19,9\right)\right)}{512} = 2,42\ kPa$$

Dew point of gas mixture may be derived from Equation (B.1), solving for t.

~~$= 280,1066 + \frac{(33,449\text{-}0,13907 * 280,1066)\log 2,42}{1 - 0,13907\log 2,42} = 293,66\ K$~~

$$= \frac{280,1066 + \left(33,449 - 0,13907 \times 280,1066\right)\log 2,42}{\left(1 - 0,13907 \log 2,42\right)} = 293,66\ K$$

Bibliography

[1] Mills I. et al., Quantities, Units and Symbols in Physical Chemistry, International Union of Pure and Applied Chemistry (IUPAC), Physical Chemistry Division, Ed.2, 1993

[2] Van Vleck J.H., *The theory of electric and magnetic susceptibilities,* Oxford University Press, 1965

[3] IEC 61115, *Expression of performance of sample handling systems for process analyzers*

[4] IEC 60654-1, *Industrial-process measurement and control equipment – Operating conditions – Part 1: Climatic conditions*

[5] ISO 9001, *Quality management systems – Requirements*

IEC 61207-3

Edition 3.0 2019-06

INTERNATIONAL STANDARD

NORME INTERNATIONALE

Gas analyzers – Expression of performance – Part 3: Paramagnetic oxygen analyzers

Analyseurs de gaz – Expression des performances – Partie 3: Analyseurs d'oxygène paramagnétiques

IEC 61207-3:2019-06(en-fr)

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

GAS ANALYZERS – EXPRESSION OF PERFORMANCE –

Part 3: Paramagnetic oxygen analyzers

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.

2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.

3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.

4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.

5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.

6) All users should ensure that they have the latest edition of this publication.

7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.

8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.

9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

International Standard IEC 61207-3 has been prepared by sub-committee 65B: Measurement and control devices, of IEC technical committee 65: Industrial-process measurement, control and automation.

This third edition cancels and replaces the second edition published in 2002. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) all references (normative and informative) have been updated, deleted or added to as appropriate;

b) all the terms, descriptions and definitions relating to the document have been updated where appropriate;

IECNORM.COM : Click to view the full PDF of IEC 61207-3:2019 RLV

c) all references to “errors” have been replaced by “uncertainties” and appropriate updated definitions applied.

The text of this International Standard is based on the following documents:

FDIS	Report on voting
65B/1155/FDIS	65B/1157/RVD

Full information on the voting for the approval of this International Standard can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

This International Standard is to be used in conjunction with IEC 61207-1:2010.

A list of all parts in the IEC 61207 series, published under the general title *Gas analyzers – Expression of performance*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

INTRODUCTION

Paramagnetic oxygen analyzers respond to the partial pressure of oxygen in the measured gas, and the volumetric concentration is then determined by knowledge of the total pressure, as in many other gas analyzers. Due to this fact, many paramagnetic oxygen analyzers use pressure compensation (see 4.4.4 and 4.4.5). They are used in a wide range of industrial, laboratory, medical, and other applications where the rated measuring range of the analyzer is between 0 % to 1 % and 0 % to 100 %, at reference pressure (usually near atmospheric).

Only a few gases display significant paramagnetism (for example, oxygen, nitric oxide and nitrogen dioxide), and oxygen has the strongest paramagnetic susceptibility (see Annex A) among gases. By employing this particular property of oxygen, analyzers have been designed that can be highly specific to the measurement in most industrial and medical applications, where, for example, high background levels of hydrocarbons or moisture may be present.

There are several different techniques described for measuring oxygen by its paramagnetic property, but three main methods have evolved over many years of commercial application.

The three methods are:

- automatic null balance;
- thermomagnetic or magnetic wind;
- differential pressure or Quincke.

These methods all require the sample gas to be clean and non-condensing, though some versions work at elevated temperatures so that samples that are likely to condense at a lower temperature can be analyzed. Because of this requirement, analyzers often require a sample system to condition the sample prior to measurement.

GAS ANALYZERS –
EXPRESSION OF PERFORMANCE –

Part 3: Paramagnetic oxygen analyzers

1 Scope

This part of IEC 61207 applies to the three main methods for measuring oxygen by its paramagnetic property, which are outlined in the introduction. It considers essential ancillary units and applies to analyzers installed indoors and outdoors.

Safety-critical applications can require additional requirements from system and analyzer specifications not covered in this document.

This document is intended

- to specify terminology and definitions related to the functional performance of paramagnetic gas analyzers for the measurement of oxygen in a source gas;
- to unify methods used in making and verifying statements on the functional performance of such analyzers;
- to specify what tests are performed to determine the functional performance and how such tests are carried out;
- to provide basic documents to support the application of internationally recognized quality management standards.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 61207-1, *Expression of performance of gas analyzers – Part 1: General*

3 Terms and definitions

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

NOTE Although cgs (centimetre-gram-second) units have been used in this document, SI (Système International) units (such as defined in IUPAC [1] [1]) can also be used.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

---

[1] Numbers in square brackets refer to the bibliography

3.1
magnetic susceptibility

measure (X) of the variation of the intensity of a magnetic field H, existing in a vacuum, when the vacuum is substituted (filled) by the test substance, expressed as:

$$X = \frac{H^1 - H}{H}$$

where

H is the magnetic field intensity in vacuum

H^1 is the magnetic field intensity in the test substance

Note 1 to entry: $H^1 - H$ is also known as the magnetisation MV (magnetic dipole per unit volume) and therefore this is also the volume magnetic susceptibility.

3.2
paramagnetism

property of substances causing an increase of the magnetic field intensity ($X > 0$)

3.3
diamagnetism

property of substances causing a diminution of the magnetic field intensity ($X < 0$ because $H^1 < H$)

3.4
specific magnetic susceptibility

ratio of magnetic susceptibility to the density derived as follows:

$$X_\mathrm{s} = \frac{X}{D}$$

where

D is the density of the considered substance, expressed in g·cm^{-3} at 273,15 K, 101,3 kPa

Note 1 to entry: The measuring unit of X_s is therefore cm^3·g^{-1}. This is also known as the mass magnetic susceptibility.

3.5
molar magnetic susceptibility

X_m

specific magnetic susceptibility multiplied by the molecular mass (M) of the substance considered:

$$X_\mathrm{m} = X_\mathrm{s} \cdot M$$

where

M is expressed in g per mole (g·mol^{-1}) (for oxygen M = 31,998 8)

Note 1 to entry: The measuring unit of X_m is therefore cm^3·mol^{-1}.

Note 2 to entry: Electrons determine the magnetic properties of matter in two ways:

- an electron can be considered as a small sphere of negative charge spinning on its axis. This spinning charge produces a magnetic moment;
- an electron travelling in an orbit around a nucleus will also produce a magnetic moment.

It is the combination of the spin moment and the orbital moment that governs the resulting magnetic properties of an individual atom or ion.

In paramagnetic materials, the main contribution to the magnetic moment comes from unpaired electrons. It is the configuration of the orbital electrons and their spin orientations that establish the paramagnetism of the oxygen molecule and distinguish it from most other gases.

Note 3 to entry: When paramagnetic gases are placed within an external magnetic field, the flux within the gas is higher than it would be in a vacuum, thus paramagnetic gases are attracted to the part of the magnetic field with the strongest magnetic flux. On the contrary, diamagnetic substances contain magnetic dipoles which cancel out some lines of force from the external field; thus diamagnetic gases are subject to repulsion by the magnetic flux.

Note 4 to entry: The molar magnetic susceptibility of oxygen is inversely proportional to the absolute temperature. According to Van Vleck [2] the molar susceptibility of oxygen can be approximated by Equation (4).

For oxygen,

$$X_m = \frac{8L \cdot \mu_B^2}{3kT} \tag{4}$$

where

X_m is the molar susceptibility of oxygen, expressed in $cm^3 \cdot mol^{-1}$;

L is the Avogadro constant = $6{,}022\,7 \times 10^{23}$ mol^{-1};

μ_B is the Bohr magneton = $9{,}274 \times 10^{-24}$ $A \cdot m^2$;

k is the Boltzmann constant = $1{,}38 \times 10^{-23}$ $J \cdot K^{-1}$;

T is the temperature, expressed in K (kelvin).

Equation (4) can be written as follows:

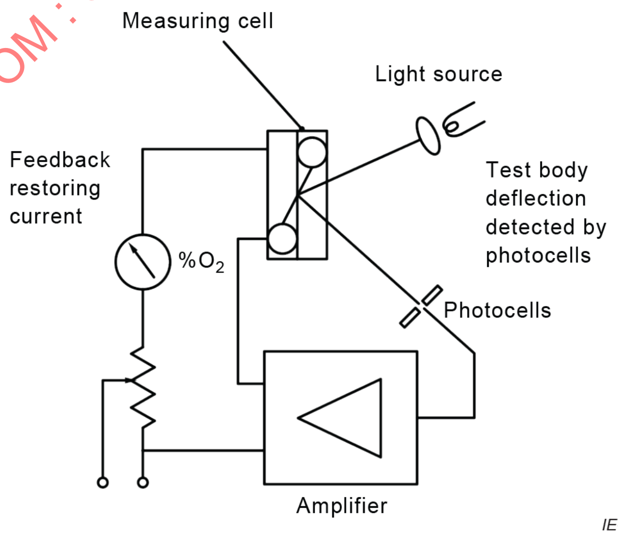
$$X_m = \frac{1010557}{T} \times 10^{-6}\ cm^3 \cdot mol^{-1} \text{ (only for oxygen).}$$

Note 5 to entry: A full understanding of paramagnetism and diamagnetism can be obtained from physics and inorganic chemistry textbooks. The explanation in this document is to give the user of paramagnetic oxygen analyzers a simple understanding of the physical property utilized.

3.6
automatic null balance analyzer

analyzer that uses, as a general principle of operation, the displacement of a body containing a vacuum or a diamagnetic gas, from a region of high magnetic field by paramagnetic oxygen molecules

Note 1 to entry: See Figure 1.



IEC

Figure 1 – Magnetic auto-balance system with current feedback

Note 2 to entry: The measuring cell typically employs a glass dumb-bell, with the spheres containing nitrogen, suspended on a torsion strip between magnetic pole pieces or magnets that produce a very strong magnetic field gradient around the dumb-bell. The dumb-bell is then deflected when oxygen molecules enter the measuring cell, a force being exerted on the dumb-bell by the oxygen molecules which are attracted to the strongest part of the magnetic field. By use of an optical lever, a magnetic actuation coil, and suitable electronics to generate a feedback signal that nulls the magnetic susceptibility force, an output that is directly proportional to the partial pressure of oxygen can be achieved. The transducer can be maintained at a constant temperature to prevent the variations in magnetic susceptibility to temperature from introducing uncertainties. Alternatively, built-in temperature sensors may be used to provide temperature compensation of the oxygen reading. Additionally, the elevated temperature helps in applications where the sample is not particularly dry. Some analyzers are designed so that the transducer operates at a temperature in excess of 373,15 K (100 °C) to further facilitate applications where condensates would form at a lower temperature. Paramagnetic sensor orientation may also affect the oxygen measurement uncertainty and this may be corrected by using a compensation algorithm using, for example, a three-dimensional accelerometer to determine the sensor orientation relative to its orientation during calibration. Due to the mechanical nature of this type of device, there is some inherent susceptibility to vibrational and gyroscopic motion, potentially resulting in increased measurement uncertainty.

3.7
thermomagnetic analyzer

3.7.1
magnetic wind analyzer

analyzer that uses the temperature dependence of the magnetic susceptibility to generate a magnetically induced gas flow which can then be measured by a flow sensor

Note 1 to entry: The sample gas passes into a chamber designed in such a way that the inlet splits the flow.

Note 2 to entry: See Figure 2.

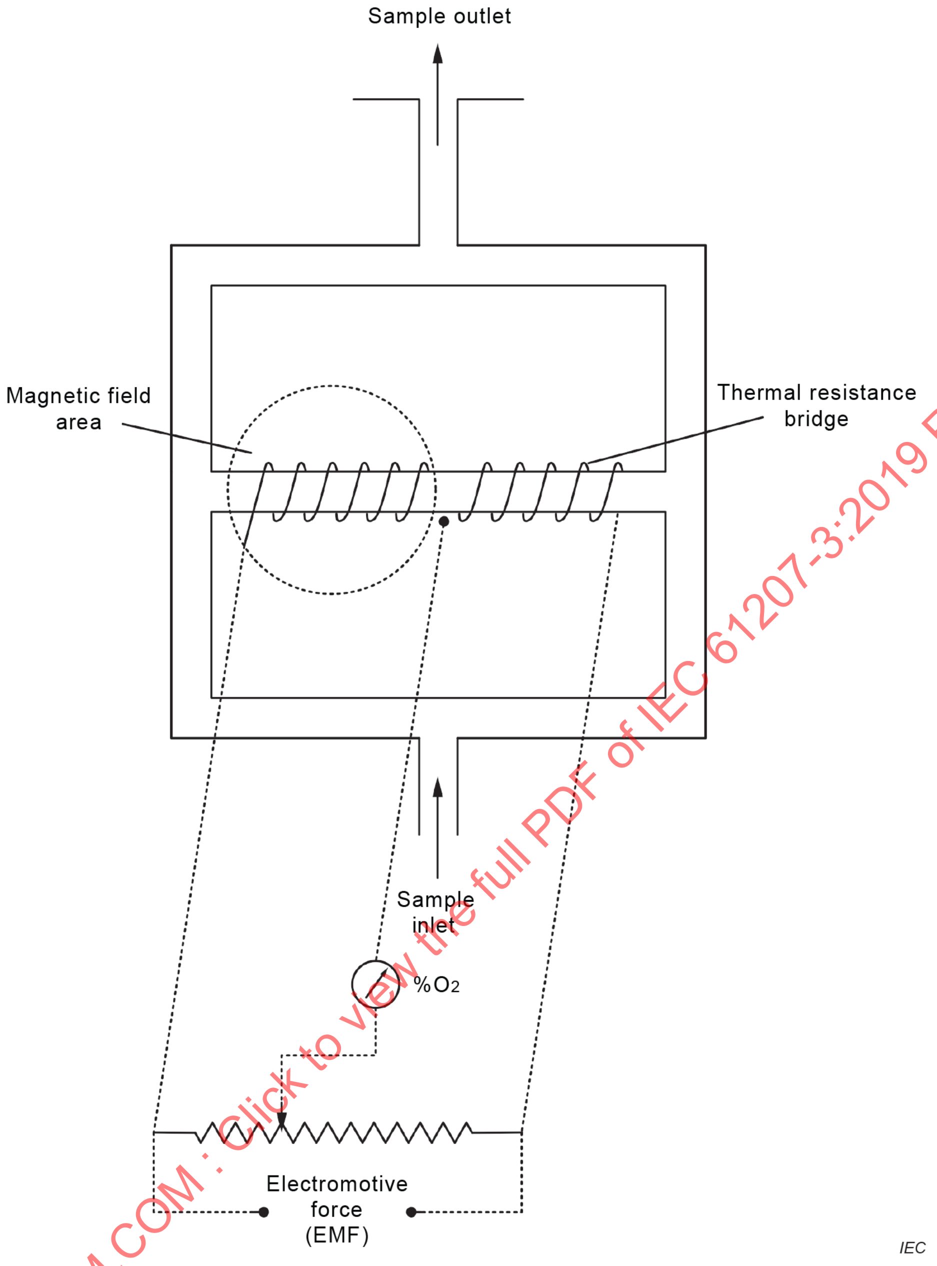


Figure 2 – Thermomagnetic oxygen sensor

Note 3 to entry: The two flows recombine at the outlet. A connecting tube is placed centrally with the flow sensor wound on it. Half of the connecting tube is placed between the poles of a strong magnet. The flow sensor is effectively two coils of wire heated to about 353,15 K (80 °C) by passage of a current. The cold oxygen molecules are diverted by the magnetic field into the central tube, and, as they heat up, their magnetic susceptibility is reduced and more cold oxygen molecules enter the connecting tube. A flow of oxygen is generated in this way through the transversal connecting tube, with the effect of cooling the first coil (which is placed in the magnetic field area), while the temperature of the second coil is not essentially influenced by this transversal flow. Since the two coils are wound with thermosensitive wire (for example, platinum wire) and connected together to build a Wheatstone bridge, the resulting unbalance current is a nearly proportional function of the oxygen partial pressure in the test gas.

More recent analyzers use more refined measuring cells, toroidal shaped resistors instead of the two-coil flow sensor, and employ temperature control to minimize ambient temperature changes.

As this method relies on heat transfer, the thermal conductivity of background gases will affect the oxygen reading and the composition of the background has to be known. Some analyzers can give a first-order correction for this by utilizing further compensation devices.

Thermomagnetic analyzers do not produce a strictly linear output and additional signal processing is required to linearize the output.

3.8
Quincke analyzer

3.8.1
differential pressure analyzer

analyzer that uses a pneumatic balance system established by using a flowing reference gas (such as nitrogen or air)

Note 1 to entry: The measuring cell is designed so that at the reference gas inlet the flow is divided into two paths. These flows recombine at the reference gas outlet, where the sample is also introduced. A differential pressure sensor (or microflow sensor) is positioned across the two reference gas flows so that any imbalance is detected. A magnet is situated in the vicinity of the reference gas outlet in one arm of the measuring cell so that oxygen in the sample is attracted into the arm, thereby causing a small back pressure which is detected by the pressure sensor (see Figure 3).

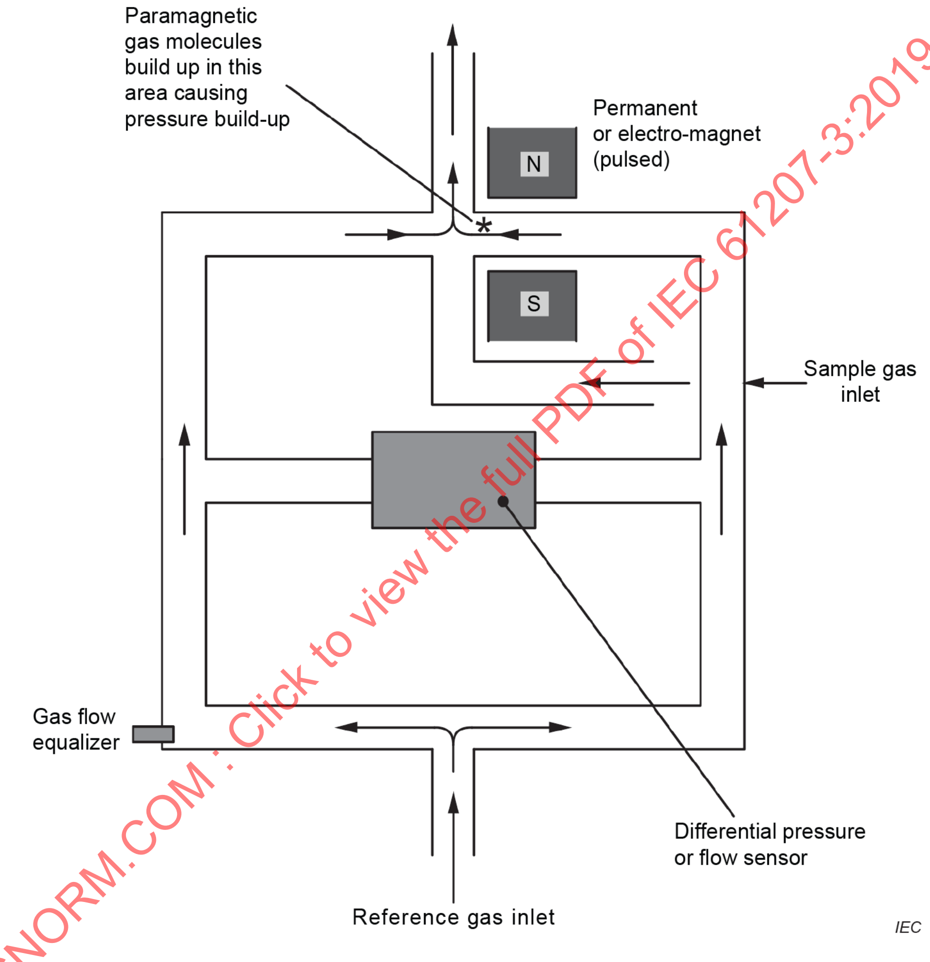


Figure 3 – Differential pressure oxygen sensor

Note 2 to entry: Differential pressure analyzers are independent of thermal conductivity of background gases, and as only the reference gas comes in contact with the sensor, corrosion problems are minimal. Some instruments use pulsed magnetic fields to improve tilt sensitivity, and certain designs compensate for vibration effects.

3.9
hazardous area

area in which an explosive gas atmosphere is present, or may be expected to be present, in quantities such as to require special precautions for the construction, installation and use of devices

3.10
essential ancillary unit

unit without which the analyzer will not operate within specifications

EXAMPLE: Calibration systems, reference gas systems, sample systems.

3.11
sample systems

system of component parts assembled on a panel or in an analyzer house with the purpose of transporting the sample gas from the sampling point to the analyzer and presenting the sample in such a manner that reliable measurements can be obtained

Note 1 to entry: The components used can include

- pressure regulators;
- flow meters;
- flow controllers;
- filtration units;
- pumps;
- valves (manual and/or electrically operated);
- catch or knockout pots;
- coolers;
- heaters;
- drying units;
- scrubbing units.

Note 2 to entry: See Figure 4 and Figure 5 for examples of typical sampling systems. For full details of sample system requirements, see IEC 61115 [3]. These components will usually be designed as a sample system by the user or, more often, by a manufacturer, so that the analyzer requirements defined in the specification are within the rated operating range. The required system design is therefore very dependent on the sample conditions of the process. Variations in sample pressure, temperature, dust loading, and pressure of other gases and vapours will affect the final sample system design.

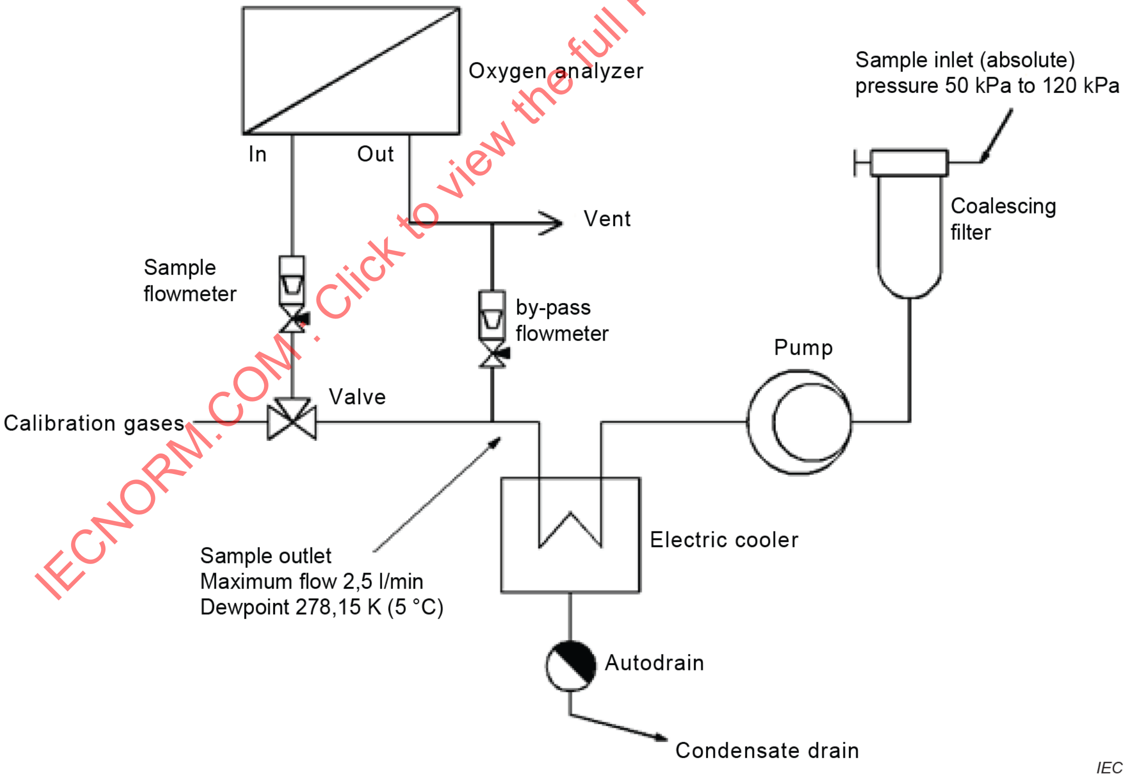


**Figure 4 – Typical sampling systems –
Filtered and dried system with pump for wet samples**

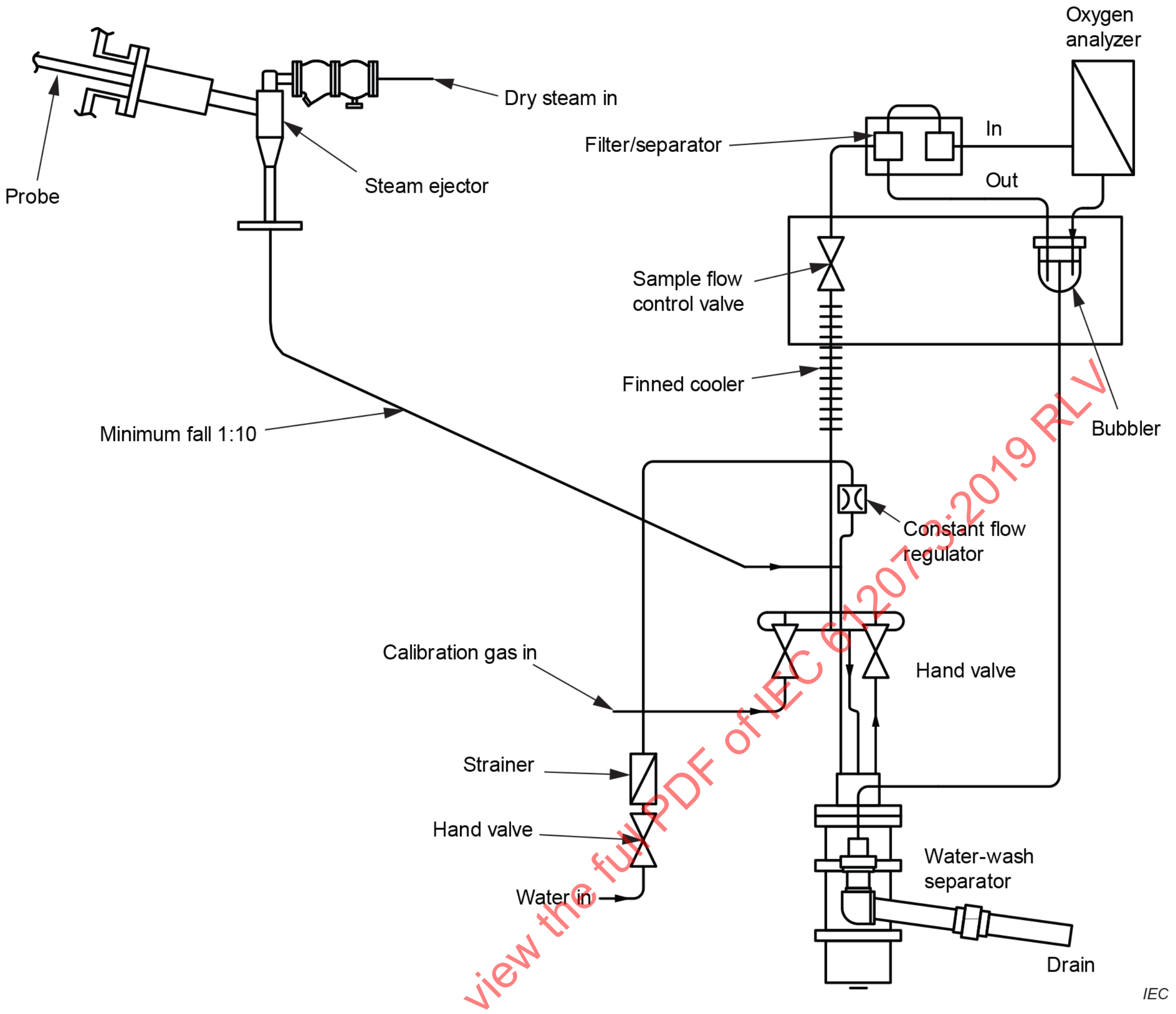


Figure 5 – Typical sampling system – Steam-aspirated system with water wash for wet samples

3.12
sample dew point

dew point of a sample expressed in K and is the temperature at or below which condensation occurs

Note 1 to entry: The analyzer should be operated at a minimum of 5 K above the sample dew point to prevent formation of condensate.

Note 2 to entry: The presence of condensation at the inlet of an analyzer will usually cause malfunction. Condensate may form from water vapour or other vapours depending on the nature of the sample.

3.13
reference gas

gas of known constant composition

Note 1 to entry: Pure nitrogen is usually employed. The reference gas can have an oxygen content, for example air. This has the effect of giving a suppressed zero and is useful when measuring high oxygen concentrations as it reduces the influence of barometric pressure.

4 Procedures for specification

4.1 General

The procedures are detailed in IEC 61207-1. This covers:

- operation and storage requirements;
- specification of ranges of measurement and output signals;
- limits of uncertainties;
- recommended reference values and rated ranges of influence quantities (see IEC 60654-1).

In this part of IEC 61207, requirements for essential ancillary units and services are given. Additional characteristics for specification of performance and important aspects of performance relevant to paramagnetic analyzers are detailed.

4.2 Specification of essential ancillary units and services

4.2.1 Sampling system

The sampling system shall be specified to supply the sample within the rated range of influence quantities of the analyzer.

Simple elements of the sampling system may be included in the analyzer. Sample flow meters, sample flow regulation, bypass flow meters, bypass flow regulations, sample filters are often part of the analyzer.

If certain system elements are included in the analyzer the rated range of influence quantities will be less severe compared to an analyzer without any sampling system.

The sampling system will add a delay in addition to the response time of the analyzer. Hence, the sample system response time should be specified.

The chemical composition of the sample stream shall be considered in the system specification. Special precautions need to be taken for flammable samples, toxic samples or corrosive samples.

Some materials are permeable to oxygen (for example, silicones) and the measurement uncertainties that may be introduced by them should be considered and avoided if necessary. For systems measuring very high concentrations of oxygen, the sampling system components should be clean for oxygen service to prevent any dangerous reactions with flammable contaminants.

4.2.2 Services

4.2.2.1 General

Paramagnetic oxygen analyzers will require facilities for calibration after installation. Bottled calibration gases and pressure regulation facilities are generally required. Quincke analyzers will additionally require facilities for supplying the reference gas.

NOTE Nitrogen is usually employed for zero calibration. The span gas will usually be a known concentration of oxygen in nitrogen typically about 80 % of the measuring range. Air contains between 20,64 % and 20,95 % O_2 by volume due to varying humidity. Dry air or instrument air at 20,95 % O_2 can therefore be used for span calibrations. If the oxygen level of the sample gas is high, then 100 % O_2 is usually used as the span gas.

4.2.2.2 Rated range of calibration and reference gas pressure

Calibration and reference gas pressure shall be within the rated range of sample pressure for the analyzer, to prevent possible damage to the paramagnetic sensor.

4.2.2.3 Rated range of calibration and reference gas flow

Calibration and reference gas flow shall be within the rated range of sample flow for the analyzer. For minimum uncertainties, the calibration gas flow should be set the same as the sample flow. Excessively high calibration and reference gas flows can damage the paramagnetic sensor, particularly from a large pressure impulse, which may occur if the flow outlet becomes blocked and then quickly released.

4.3 Additional characteristics related to specification of performance

4.3.1 The following additional characteristics to those detailed in IEC 61207-1 may be required to be specified to define the performance of a paramagnetic analyzer or its suitability for a particular application. Depending on the analyzer design details or application, some of these additional terms may be omitted.

4.3.2 Hazardous classification of the area in which the analyzer is to be located. General purpose analyzers will not be suitable for location in hazardous areas.

4.3.3 Flammable gases or vapours should only be sampled by analyzers which are specified as suitable and should be vented from the analyzer in a safe manner.

4.3.4 If the sample gas is toxic, this should be specified, as special maintenance instructions may be required to ensure leak-free operation. Installation of the analyzer shall also take into account how the sample gas is vented, returned to process, or otherwise dealt with.

4.3.5 The orientation of the analyzer should be considered. In fixed installations, analyzers should be positioned in an upright manner so that any uncertainties due to tilt are minimized. For installations that move (for example, ships), the rated range of tilt should be specified.

4.3.6 The vibration sensitivity of the analyzer should be considered. For applications where the vibration levels are outside the rated range of the analyzer, anti-vibration mountings are recommended.

4.3.7 The response time of the analyzer and its sampling system should be considered. The response time specified for the analyzer will usually be considerably less than the sampling system, but is dependent on the sampling system design.

NOTE Some paramagnetic analyzers are designed with adjustable sample flow and bypass flow sample systems.

4.4 Important aspects related to specification of performance

4.4.1 General

Although covered in IEC 61207-1, the following aspects are particularly relevant to paramagnetic analyzers.

4.4.2 Rated range of ambient temperature

The performance of an analyzer is normally ambient temperature-dependent and will have a defined operating range of temperatures within which it will operate within its specification.

4.4.3 Rated range of sample gas temperature

The magnetic susceptibility of oxygen is temperature-dependent, and large uncertainties in the measurement value occur unless the analyzer is designed to compensate for the temperature of the sensor. In practice, the temperature of the paramagnetic sensor will depend on ambient temperature and gas temperature. Process paramagnetic oxygen analyzers usually employ temperature-controlled sensors (in addition to temperature compensation) to minimize effects of sample temperature changes and ambient temperature changes. Simple analyzers may not have temperature-controlled sensors, in which case calibration should precede measurements so that ambient temperature effects and sample temperature effects are taken into account.

4.4.4 Rated range of ambient pressure

Measurement values are dependent on sample pressure. If the analyzer is vented to atmosphere, so that the sample within the sensor is at ambient pressure, changes in barometric reading will cause uncertainties in the measured value. For analyzers where the measured value is directly proportional to the sample pressure (automatic null balance analyzer), uncertainty can occur in O_2 readings (% O_2),

$$\Delta O_\mathrm{m} = \frac{P_\mathrm{m} - P_\mathrm{c}}{P_\mathrm{c}} \times O_\mathrm{m} \tag{5}$$

where

O_m is the oxygen reading at time of measurement in % O_2;

P_m is the absolute ambient pressure at time of measurement in kPa;

P_c is the absolute ambient pressure at time of calibration in kPa.

Barometric pressure compensation is usually offered by manufacturers to minimize this type of uncertainty.

4.4.5 Rated range of sample pressure

If the sample is returned to the process stream (assuming process pressure is within the rated range of sample pressure), variations in process pressure will cause similar uncertainties to those described in 4.4.4.

Sample pressure compensation is usually offered by manufacturers of process analyzers so that this type of uncertainty is minimized.

4.4.6 Rated range of sample flow

Uncertainties in indicated value due to sample flow can be minimized by setting the calibration flow rates to the expected sample flow rates.

4.4.7 Rated range of sample dew point

Samples shall be supplied within the rated range of the sample dew point to increase performance reliability. Also, differences in indicated value will occur if the measurement is made on a wet basis compared to a dry basis.

NOTE 1 If the rated range of sample dew point for an analyzer is low, then the sampling system can have to remove water vapour from the sample. If, for example, 10 % water vapour were removed by the sample system, the corresponding indicated oxygen value would be 100/90 times greater than the value in the wet sample.

NOTE 2 Some oxygen analyzers are designed so that the sensor is controlled at temperatures within the range 333,15 K to 393,15 K (60 °C to 120 °C). This will enable relatively wet samples to be analyzed reliably. For example, a sample saturated with water vapour at 294,15 K (21 °C) contains approximately 2,5 % water vapour. This wet sample would normally be within the rated range of the sample dew point for an analyzer wherein the sensor is controlled at 333,15 K (60 °C). However, the water content in the sample will produce a volumetric error compared to a measurement made on a dry basis where the water has been removed prior to measurement.

4.4.8 Rated range of sample particulate content

Paramagnetic oxygen analyzers usually require a relatively clean sample to ensure reliable operation. The rated range of particulates defined in mass per cubic metre (mg/m^3), and maximum particulate size in microns (µm) should not be exceeded.

4.4.9 Rated range of interference uncertainties

Paramagnetic oxygen analyzers are by design specifically measuring the magnetism of the sample gas. Oxygen has a high magnetic susceptibility and the measurement is therefore quite specific, but see Annex A for interferences of other common gases. Nitrogen oxide, in particular, has a significant cross-interference.

Some oxygen analyzers will have interference uncertainties from properties of gases other than the magnetic susceptibility. For example, gases of high thermal conductivity in the sample may introduce uncertainties in the indicated value in magnetic wind analyzers, though modern analyzers may partially compensate for this.

Water vapour content shall be in the rated range of the sample dew point (see 4.4.7). Interference uncertainties, other than those due to volumetric effects, may occur.

4.4.10 Rated range of linearity uncertainty

Some analyzers are inherently linear and have very small linearity uncertainties.

4.4.11 Rated ranges of influence quantities

Ranges for climatic conditions, mechanical conditions and main supply conditions are specified in IEC 60654-1.

NOTE In addition, paramagnetic oxygen analyzers can be affected by the presence of nearby magnetic fields.

5 Procedures for compliance testing

5.1 Analyzer testing

5.1.1 General

The tests considered in Clause 5 apply to the complete analyzer as supplied by the manufacturer and include all essential ancillary equipment. The analyzer will be set up by the manufacturer, or in accordance with his instruction, prior to testing.

5.1.2 Test equipment

The following test equipment for verification of values that confirm the performance of paramagnetic oxygen analyzers will be required.

a) Gas mixing equipment to prepare the required test gases (certified calibration gases can be used).

b) Equipment to present the test gases to the analyzer at the required pressure, flow and temperature. Gases have to be switched over to enable response time measurements.

c) Equipment to measure interference uncertainties. This will also include temperature controlled bubblers or other moisture generation equipment so that the effects of water vapour can be measured.

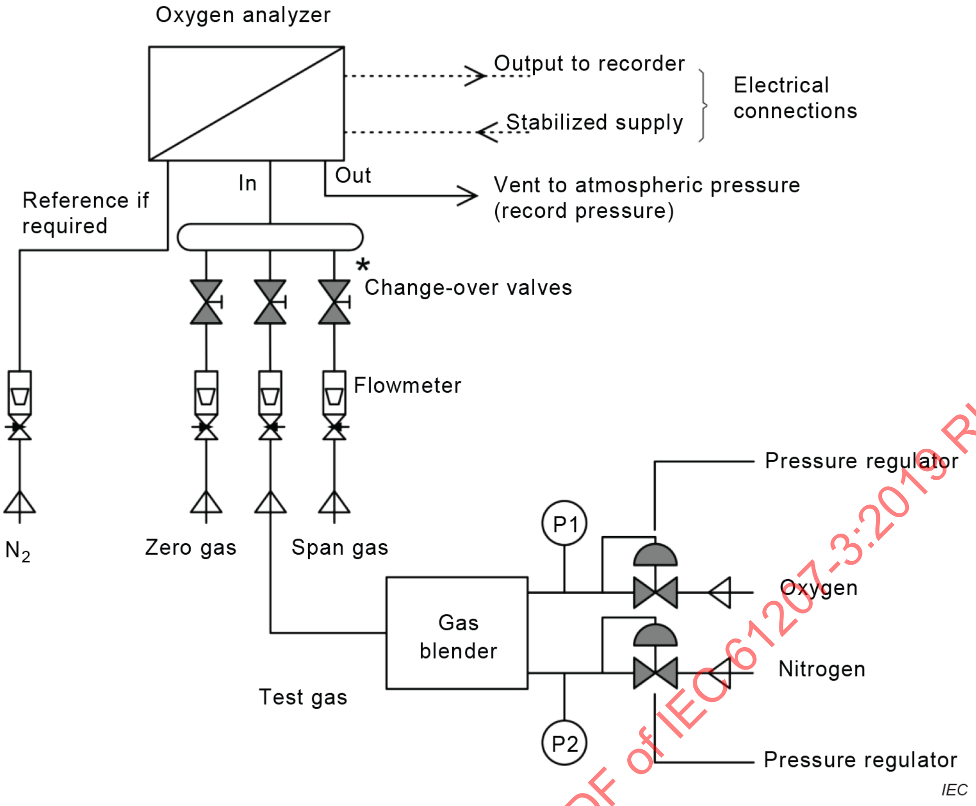
d) An environmental chamber will be required to measure appropriate influence uncertainties, such as temperature or humidity.

e) Equipment for determining influence quantities from variation in supply voltage, frequency and supply interruption.

f) Equipment to determine influence uncertainties due to electromagnetic susceptibility. Radiated emissions may have to be determined.

g) Equipment to determine influence uncertainties under vibration.

Figure 6 shows the general test arrangement for dry gases.



* Dead space to be minimized to avoid uncertainties in response time measurement.

Figure 6 – General test arrangement – Dry gases

5.2 Testing procedures

5.2.1 General

The following relevant testing procedures are detailed in IEC 61207-1.

- Intrinsic uncertainty.
- Linearity uncertainty.
- Repeatability uncertainty.
- Output fluctuation.
- Drift.
- Delay time, rise time, fall time.
- Warm-up time.
- Variations (influence uncertainties).
- Interference uncertainties.

Any ancillary equipment for the correct functioning of the analyzer will be kept under reference conditions.

Additional test details required for paramagnetic oxygen analyzers are given below.

5.2.2 Interference uncertainty

The value for testing and the statement of interference uncertainties shall be agreed between the manufacturer and user prior to testing.

The manufacturer bears an obligation to indicate components (and their concentrations) and parameters which are expected, from experience, to provide interference equal to, or greater than, the minimum detectable concentration. This will include sample pressure if pressure compensation is not provided.

Interference uncertainties are determined by first presenting the analyzer with the calibration gas and then sequentially with gases that contain the highest expected concentration of interfering components, and then at half that level, and which are otherwise identical to the calibration gas.

Zero calibration gas may be used where the interference uncertainty is not expected to vary significantly through the effective range.

Each test is repeated three times, and the average uncertainties are determined and recorded in terms of the equivalent concentration of the component to be determined.

5.2.3 Wet samples

If it is required that tests are performed on the rated range of the dew point, or to measure interference uncertainties due to water vapour, the following is relevant.

Water vapour interference, after allowance for dilution, can be determined by the same procedure as stated in 5.2.2. However, the method of preparation of gases with a known concentration of water vapour requires special equipment such as shown in Figure 7 or by using another suitable system. Examples of calculations of water vapour content using the equipment of Figure 7 are shown in Annex B.

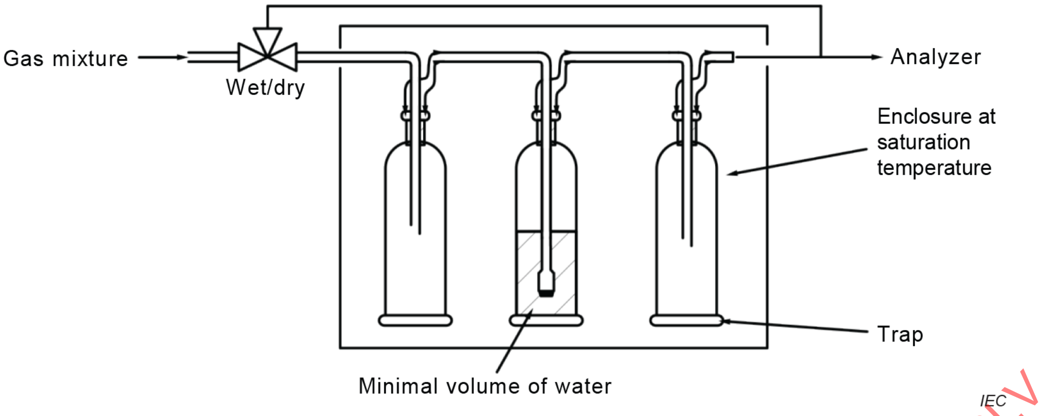
All pipework from the point of water vapour or other condensable vapour addition, up to the analyzer sample inlet, shall be maintained above the dew point.

The reference conditions will be with dry test gases.

For analyzers requiring testing at high dew points, the bubbler and sample pipework and cell may be operated at elevated temperatures. The partial pressure for water vapour may be calculated over the range 273,15 K to 373,15 K (0 °C to 100 °C) as in Equation (B.1).

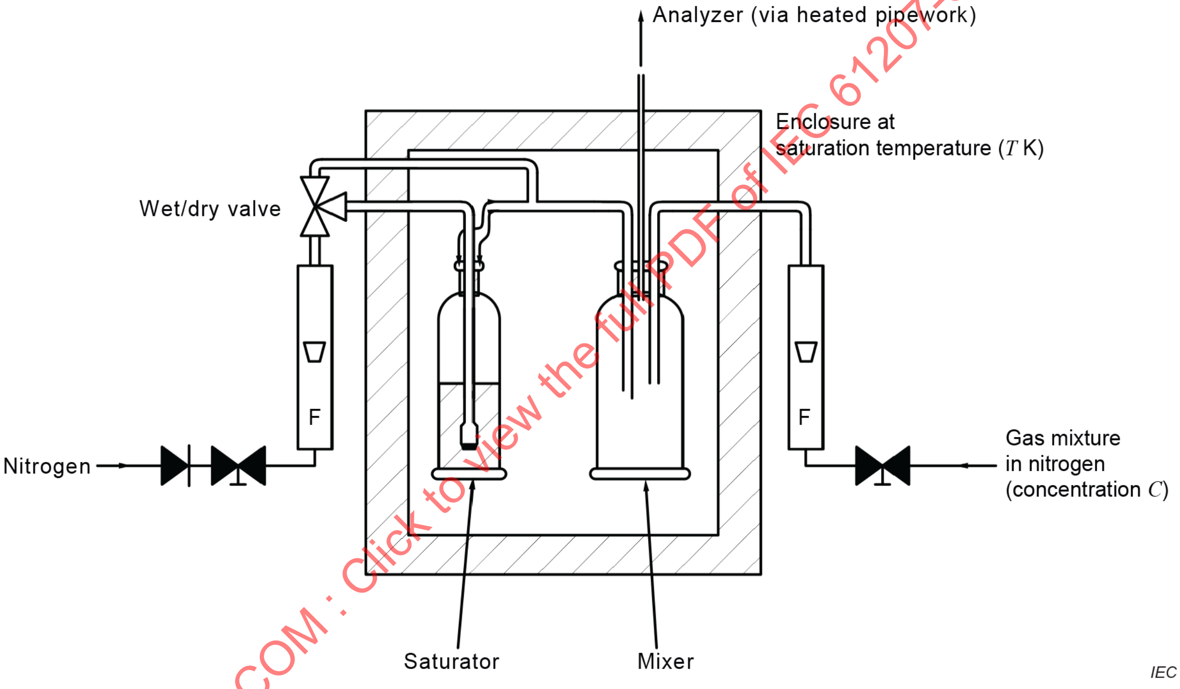
5.2.4 Delay times, rise time, fall time

In determining these response times, it is important to consider the effects of the sample pipe and components as the stated values will be specified at the sample inlet of the analyzer. Also, stated response values will usually require that sample flow rate is at the maximum within its rated range and the same applies to the bypass flow if this function is fitted to the analyzer.



Enclose trap only for temperatures below 273 K. Long equilibration times will be required. All gas mixture components shall be insoluble.

a) Simple bubbler to apply water vapour to sampling systems



Pipework/components to be in stainless steel, glass, PTFE.

b) Apparatus to apply water vapour at high concentrations or to avoid long equilibration times

Figure 7 – Test apparatus to apply gases and water vapour to analysis systems

Annex A
(informative)

Interfering gases

Oxygen is a paramagnetic gas, i.e. it is attracted into a magnetic field. Virtually all other gases are diamagnetic, i.e. repelled from a magnetic field. Paramagnetic oxygen analyzers are usually calibrated on a scale which is normalized for nitrogen at 0 and oxygen at 100. For highly accurate measurements, it may be necessary to introduce a zero offset into the calibration to compensate for the background gas. Table A.1 gives the correction factors for many common gases. Some values given are calculated, others measured, and as such, should be considered as indicative rather than absolute values.

Example 1: an analyzer calibrated with nitrogen as the zero gas and oxygen as the span gas will, when 100 % carbon dioxide is passed through it, show a reading of –0,30 % O_2. If the purpose is to measure oxygen in carbon dioxide then this will give an uncertainty. There are two ways to compensate for this.

a) Carbon dioxide is used as the zero gas.

b) Nitrogen is used as the zero gas, but the zero is set to an offset equal but opposite to the background gas (i.e. +0,30 % O_2).

Example 2: if the background gas is a mixture, then the proportional sum of the zero uncertainties is used to calculate the zero offset. Assuming N_2 is used as the zero gas, and that the background gas is composed of 12 % CO_2, 5 % CO, 5 % n-Octane, 78 % N_2, the zero offset will be:

12 % CO_2 = 12 % of −0,30 = −0,04
5 % CO = 5 % of +0,07 = +0,00
5 % n-Octane = 5 % of −2,78 = −0,14
78 % N_2 = 78 % of 0,00 = +0,00
Total: = −0,18

In this case, zero offset would be set at +0,18.

Alternatively, as in Example 1, the actual background gas could be used as the zero gas.

NOTE 1 Nitrogen dioxide exists in equilibrium with dinitrogen tetroxide. The relative proportions vary greatly with temperature between 253,15 K (−20 °C) and 403,15 K (130 °C). As nitrogen dioxide is paramagnetic and dinitrogen tetroxide is diamagnetic, the relative molar susceptibility of the equilibrium gas also varies. The value of the molar magnetic susceptibility of nitrogen dioxide in Table A.1 is at 408,15 K (135 °C). The zero uncertainty at 333,15 K (60 °C) is estimated and depends considerably on the equilibrium ratio of nitrogen dioxide and dinitrogen tetroxide at 333,15 K (60 °C).

NOTE 2 In Table A.1, the zero uncertainty assumes 100 % by volume of interference gas as it is at 333,15 K (60 °C). Data for other temperatures is available from some instrument manufacturers and for other gases not listed.

The molar magnetic susceptibility is largely independent of temperature for diamagnetic substances and is negative. Only three gases in Table A.1 are paramagnetic, having a positive molar molecular susceptibility. These are oxygen, nitrogen dioxide and nitric oxide. In these cases, the value of molar magnetic susceptibility is dependent on temperature (for example see Equation (4) for oxygen), and the values are given for 293,15 K (20 °C) apart from nitrogen dioxide (408,15 K (135 °C)). (See Note 1 above.)

Table A.1 – Zero correction factors for current gases

Gas	**Formula**	**Molar magnetic susceptibility $\times 10^{-6}$ cm^3.mol^{-1}**	**Zero error at 60 °C**
Acetaldehyde	CH_3CHO	−22,70	−0,35
Acetic acid	CH_3CO_2H	−31,50	−0,64
Acetone	CH_3COCH_3	−33,70	−0,71
Acetylene	$HCCH$	−20,80	−0,29
Acrylonitrile	$CH_2 = CHCN$	−24,10	−0,40
Ammonia	NH_3	−18,00	−0,20
Argon	Ar	−19,60	−0,25
Benzene	C_6H_6	−54,84	−1,41
Boron chloride	BCl_3	−59,90	−1,57
Bromine	Br_2	−73,50	−2,02
n-Butane	C_4H_{10}	−50,30	−1,26
Isobutane	$(CH_3)_2CHCH_2$	−51,70	−1,30
Butene-1 (ethylacetylene)	$CH_3CH_2CH = CH_2$	−41,10	−0,96
Iso-Butylene	$(CH_3)_2CH = CH_2$	−44,40	−1,06
Butyne-1	$CH_3C_3H_2$	−43,50	−1,03
Carbon dioxide	CO_2	−21,00	−0,30
Carbon disulfide	CS_2	−42,20	−0,99
Carbon monoxide	CO	−9,80	0,07
Carbon tetrachloride	CCl_4	−66,60	−1,79
Carbon tetrafluoride	CF_4	−31,20	−0,63
Chlorine	Cl_2	−40,50	−0,94
Chloroform	$CHCl_3$	−59,30	−1,55
Cyclohexane	C_6H_{12}	−68,13	−1,84
Cyclopentane	C_5H_{10}	−59,18	−1,55
Cyclopropane	C_3H_6	−39,90	−0,92
Cumene	$(CH_3)_2CHC_6H_5$	−89,53	−2,55
Diacetylene	C_4H_2	−37,50	−0,84
Dichloroethylene	$(CHCl)_2$	−49,20	−1,22
2,2-Difluoro-1-chloroethane	$CClH_2$-CHF_2	−52,40	−1,33
1,2-Difluoro-1,2-dichloroethylene	$CFCl = CFCl$	−60,00	−1,58
Difluoro-dichloro-methane (Freon 12)	CCl_2F_2	−52,20	−1,32
Dimethoxy methane	$CH_2(OCH_3)_2$	−47,30	−1,16
Dimethylamine	$(CH_3)_2NH$	−39,90	−0,92
Dimethylether	CH_3OCH_3	−26,30	−0,47
Dimethylethylamine	$(CH_3)_2NC_2H_5$	−63,60	−1,69
Ethane	CH_3CH_3	−26,80	−0,49
Ethanol	CH_3CH_2OH	−33,60	−0,71
Ethylamine	$C_2H_5NH_2$	−39,90	−0,92
Ethylbenzene	$C_6H_5CH_2CH_3$	−77,20	−2,14
Ethylbromide	CH_3CH_2Br	−54,70	−1,40
Ethylchloride	CH_3CH_2Cl	−46,00	−1,12

Gas	Formula	Molar magnetic susceptibility × 10^{-6} $cm^3.mol^{-1}$	Zero error at 60 °C
Ethylene	CH_2CH_2	−18,80	−0,22
Ethylene glycol	CH_2OHCH_2OH	−38,80	−0,88
Ethylene oxide	$(CH_2)_2O$	−30,70	−0,61
Ethylmercaptan	$C_2H_5OSO_3H$	−47,00	−1,15
Fluorochlorobromo-methane	CFClBrH	−58,00	−1,51
Fluorodichloro-methane (Freon 21)	Cl_2CHF	−48,80	−1,21
Furan	C_4H_4O	−43,09	−1,02
Halothane	$C_2HBrClF_3$	−78,80	−2,19
Helium	He	−1,88	0,33
n-heptane	$CH_3(CH_2)_3CH_3$	−85,24	−2,40
n-hexane	$CH_3(CH_2)_3CH_4$	−73,60	−2,02
Hydrogen	H_2	−3,98	0,26
Hydrogen Bromide	HBr	−35,30	−0,76
Hydrogen Chloride	HCl	−22,60	−0,35
Hydrogen iodide	HI	−48,20	−1,19
Hydrogen selenide	H_2Se	−39,20	−0,89
Hydrogen sulphide	H_2S	−25,50	−0,44
Isoprene	C_5H_8	−44,80	−1,08
Isopropanol	$(CH_3)_2CHOH$	−47,60	−1,17
Ketene	CH_2CO	−15,70	−0,12
Krypton	Kr	−28,80	−0,55
Methane	CH_4	−17,40	−0,18
Methyl acetate	CH_3COCH_3	−42,60	−1,00
Methanol	CH_3OH	−21,40	−0,31
Methyl cyclopentane	C_6H_{12}	−70,20	−1,91
Methylene chloride	CH_2Cl_2	−46,60	−1,14
Methylethyl ketone	$CH_3COCH_2CH_3$	−45,50	−1,10
Methyl fluoride	CH_3F	−25,50	−0,44
Methyl formate	$HCOOCH_3$	−32,00	−0,66
Methyl iodide	CH_3I	−57,20	−1,48
Methyl iso-butyl ketone (MIBK)	$C_4H_9COCH_3$	−69,30	−1,88
Methyl mercaptane	CH_3SH	−35,30	−0,76
Molybdenum hexafluoride	MoF_6	−26,00	−0,46
Neon	Ne	−6,70	0,17
Nitric oxide	NO	1 461,00	42,94
Nitrous oxide	N_2O	−18,90	−0,23
Nitrogen	N_2	−12,00	0,00
Nitrogen dioxide	NO_2	150,00	20,00
n-Nonane	C_9H_{20}	−108,13	−3,16
n-Octane	C_8H_{18}	−96,63	−2,78
Oxygen	O_2	3 449,00	100,00
n-Pentane	C_5H_{12}	−63,10	−1,68

Gas	**Formula**	**Molar magnetic susceptibility × 10^{-6} $cm^3.mol^{-1}$**	**Zero error at 60 °C**
Phenol	C_6H_5OH	−60,21	−1,58
Phosphine	PH_3	−26,00	−0,46
Propane	C_3H_8	−38,60	−0,87
Propene	$CH_3CH = CH_2$	−31,50	−0,64
Propylamine	$C_3H_7NH_2$	−52,40	−1,33
Propyl chloride	C_3H_7Cl	−56,10	−1,45
Propylene	C_3H_6	−31,50	−0,64
Propylene oxide	OCH_2CHCH_3	−42,50	−1,00
Propyl fluoride	C_3H_7F	−52,20	−1,32
Silane	SiH_4	−20,50	−0,28
Styrene	$C_6H_5CH = CH_2$	−68,20	−1,85
Sulphur dioxide	SO_2	−18,20	−0,20
Sulphur hexafluoride	SF_6	−44,00	−1,05
Tetrachloroethylene	$Cl_2C = CCl_2$	−81,60	−2,28
Tetrahydrofuran	C_4H_8O	−52,00	−1,31
Toluene	$C_6H_5CH_3$	−66,11	−1,78
Trichloro-ethylene	$CHCl = CCl_2$	−65,80	−1,77
Trifluoro-chloro-ethylene	C_2F_3Cl	−49,10	−1,22
1,1,2-Trichloro-ethane (Freon 113)	$CHCl_2\text{-}CH_2Cl$	−66,20	−1,78
Trimethylamine	$(CH_3)_3N$	−51,70	−1,30
Tungstenfluoride	WF_6	−40,00	−0,92
Urethane	$CO(NH_2)OC_2H_5$	−57,00	−1,48
Vinyl bromide	$CH_2 = CHBr$	−44,80	−1,08
Vinyl chloride	$CH_2 = CHCl$	−35,60	−0,77
Vinyl fluoride	$CH_2 = CHF$	−28,80	−0,55
Water	H_2O	−13,00	−0,03
Xenon	Xe	−43,90	−1,05
Xylene	$(CH_3)_2C_6H_4$	−77,78	−2,16
Molar magnetic susceptibility values in Table A.1 should be considered as indicative rather than absolute values.			

Annex B
(informative)

Methods of preparation of water vapour in test gases

For water vapour:

$$\text{Partial pressure} = \text{Antilog}_{10} \frac{(t-280{,}1066)}{33{,}449+0{,}13907(t-280{,}1066)} \text{ kPa} \qquad \text{(B.1)}$$

where

t is the dewpoint temperature, in K.

For mixing dry gases and water vapour in pipework above 373,15 K (100 °C), see Figure 7.

$$C_{\text{water}} = \frac{0{,}455\,MT}{(f+0{,}00455\,MT)}$$

$$C_x = \frac{C1_x}{100}\left(100 - C_{\text{water}}\right)$$

where

C_{water} is the concentration of water vapour in the final gas mixture, in per cent at 101,3 kPa;

$C1_x$ is the concentration of component x in the dry gas prior to mixing with water, in any units;

C_x is the concentration x in the final gas mixture, in the same units as $C1_x$;

M is the rate of addition of liquid water, in grams per unit time;

f is the flow rate of dry gas to the mixing point, in cm^3 per unit time;

T is the measurement temperature to which f refers, in K.

Example for Figure 7a).

The solubility of acidic gases is much reduced if the pH of the water is reduced to below 2 by the addition of sulphuric acid. The effect on vapour pressure in the range 0,01 to 0,1 molar sulphuric acid is less than 1 %.

At saturation temperature = 288,15 K (15 °C) from Equation (B.1), the partial pressure of water vapour is:

$$\text{Antilog}_{10} \frac{(288{,}15-280{,}1066)}{33{,}449+0{,}13907(288{,}15-280{,}1066)} \text{ kPa} = 1{,}71 \text{ kPa}$$

For gas passing through the bubbler at a pressure of 101,3 kPa:

$$\text{Concentration} = \frac{1{,}71}{101{,}3} \times 100 = 1{,}69\ \%$$

Dilution ratio = 1 − 0,016 9 = 0,983

Example for Figure 7b).

At saturation temperature = 333,15 K (60 °C), partial pressure of water vapour from Equation (B.1) is 19,9 kPa.

For a dry flow of 450 $\text{cm}^3\cdot\text{min}^{-1}$ and a gas flow into the bubbler of 50 $\text{cm}^3\cdot\text{min}^{-1}$, this latter flow expands under constant pressure because of the contribution from water vapour to the total pressure:

$$\text{Final gas volume flow} = 50 \times \frac{101,3}{(101,3 - 19,9)} + 450\ \text{cm}^3\cdot\text{min}^{-1} = 512\ \text{cm}^3\cdot\text{min}^{-1}$$

$$\text{Dilution ratio} = \frac{450}{512} = 0,879$$

Partial pressure of water vapour in gas mixture

$$= \frac{19,9 \times 50\left(101,3/\left(101,3 - 19,9\right)\right)}{512} = 2,42\ \text{kPa}$$

Dew point of gas mixture may be derived from Equation (B.1), solving for t.

$$= \frac{280,1066 + \left(33,449 - 0,13907 \times 280,1066\right)\log 2,42}{\left(1 - 0,13907 \log 2,42\right)} = 293,66\ \text{K}$$

Bibliography

[1] Mills I. et al., Quantities, Units and Symbols in Physical Chemistry, International Union of Pure and Applied Chemistry (IUPAC), Physical Chemistry Division, Ed.2, 1993

[2] Van Vleck J.H., *The theory of electric and magnetic susceptibilities,* Oxford University Press*,* 1965

[3] IEC 61115, *Expression of performance of sample handling systems for process analyzers*

[4] IEC 60654-1, *Industrial-process measurement and control equipment – Operating conditions – Part 1: Climatic conditions*

[5] ISO 9001, *Quality management systems – Requirements*

SOMMAIRE

COMMISSION ÉLECTROTECHNIQUE INTERNATIONALE

ANALYSEURS DE GAZ – EXPRESSION DES PERFORMANCES –

Partie 3: Analyseurs d'oxygène paramagnétiques

AVANT-PROPOS

1) La Commission Electrotechnique Internationale (IEC) est une organisation mondiale de normalisation composée de l'ensemble des comités électrotechniques nationaux (Comités nationaux de l'IEC). L'IEC a pour objet de favoriser la coopération internationale pour toutes les questions de normalisation dans les domaines de l'électricité et de l'électronique. À cet effet, l'IEC – entre autres activités – publie des Normes internationales, des Spécifications techniques, des Rapports techniques, des Spécifications accessibles au public (PAS) et des Guides (ci-après dénommés "Publication(s) de l'IEC"). Leur élaboration est confiée à des comités d'études, aux travaux desquels tout Comité national intéressé par le sujet traité peut participer. Les organisations internationales, gouvernementales et non gouvernementales, en liaison avec l'IEC, participent également aux travaux. L'IEC collabore étroitement avec l'Organisation Internationale de Normalisation (ISO), selon des conditions fixées par accord entre les deux organisations.
2) Les décisions ou accords officiels de l'IEC concernant les questions techniques représentent, dans la mesure du possible, un accord international sur les sujets étudiés, étant donné que les Comités nationaux de l'IEC intéressés sont représentés dans chaque comité d'études.
3) Les Publications de l'IEC se présentent sous la forme de recommandations internationales et sont agréées comme telles par les Comités nationaux de l'IEC. Tous les efforts raisonnables sont entrepris afin que l'IEC s'assure de l'exactitude du contenu technique de ses publications; l'IEC ne peut pas être tenue responsable de l'éventuelle mauvaise utilisation ou interprétation qui en est faite par un quelconque utilisateur final.
4) Dans le but d'encourager l'uniformité internationale, les Comités nationaux de l'IEC s'engagent, dans toute la mesure possible, à appliquer de façon transparente les Publications de l'IEC dans leurs publications nationales et régionales. Toutes divergences entre toutes Publications de l'IEC et toutes publications nationales ou régionales correspondantes doivent être indiquées en termes clairs dans ces dernières.
5) L'IEC elle-même ne fournit aucune attestation de conformité. Des organismes de certification indépendants fournissent des services d'évaluation de conformité et, dans certains secteurs, accèdent aux marques de conformité de l'IEC. L'IEC n'est responsable d'aucun des services effectués par les organismes de certification indépendants.
6) Tous les utilisateurs doivent s'assurer qu'ils sont en possession de la dernière édition de cette publication.
7) Aucune responsabilité ne doit être imputée à l'IEC, à ses administrateurs, employés, auxiliaires ou mandataires, y compris ses experts particuliers et les membres de ses comités d'études et des Comités nationaux de l'IEC, pour tout préjudice causé en cas de dommages corporels et matériels, ou de tout autre dommage de quelque nature que ce soit, directe ou indirecte, ou pour supporter les coûts (y compris les frais de justice) et les dépenses découlant de la publication ou de l'utilisation de cette Publication de l'IEC ou de toute autre Publication de l'IEC, ou au crédit qui lui est accordé.
8) L'attention est attirée sur les références normatives citées dans cette publication. L'utilisation de publications référencées est obligatoire pour une application correcte de la présente publication.
9) L'attention est attirée sur le fait que certains des éléments de la présente Publication de l'IEC peuvent faire l'objet de droits de brevet. L'IEC ne saurait être tenue pour responsable de ne pas avoir identifié de tels droits de brevet et de ne pas avoir signalé leur existence.

La Norme internationale IEC 61207-3 a été établie par le sous-comité 65B: Équipements de mesure et de contrôle-commande du comité d'études 65 de l'IEC: Mesure, commande et automation dans les processus industriels.

Cette troisième édition annule et remplace la deuxième édition parue en 2002. Cette édition constitue une révision technique.

Cette édition inclut les modifications techniques majeures suivantes par rapport à l'édition précédente:

a) toutes les références (normatives et informatives) ont été mises à jour, retirées ou ajoutées comme il convient;

b) tous les termes, descriptions et définitions en rapport avec le document ont été mis à jour le cas échéant;

c) toutes les références aux "erreurs" ont été remplacées par le terme «incertitudes» et les définitions ont été mises à jour comme il convient.

Le texte de cette Norme internationale est issu des documents suivants:

FDIS	Rapport de vote
65B/1155/FDIS	65B/1157/RVD

Le rapport de vote indiqué dans le tableau ci-dessus donne toute information sur le vote ayant abouti à l'approbation de cette Norme internationale.

Ce document a été rédigé selon les Directives ISO/IEC, Partie 2.

Cette Norme Internationale doit être utilisée conjointement avec l'IEC 61207-1:2010.

Une liste de toutes les parties de la série IEC 61207, publiées sous le titre général *Analyseurs de gaz – Expression des performances*, peut être consultée sur le site web de l'IEC.

Le comité a décidé que le contenu de ce document ne sera pas modifié avant la date de stabilité indiquée sur le site web de l'IEC sous "http://webstore.iec.ch" dans les données relatives au document recherché. À cette date, le document sera

- reconduit,
- supprimé,
- remplacé par une édition révisée, ou
- amendé.

INTRODUCTION

Les analyseurs d’oxygène paramagnétiques sont sensibles à la pression partielle de l’oxygène dans le gaz mesuré, de ce fait la concentration volumétrique est déterminée sur la base de la pression totale, comme dans de nombreux autres analyseurs de gaz. Par conséquent, de nombreux analyseurs d'oxygène paramagnétiques utilisent la compensation de la pression (voir 4.4.4 et 4.4.5). Les analyseurs d’oxygène paramagnétiques sont utilisés pour de nombreuses applications industrielles, médicales, de laboratoire et autres pour lesquelles l’étendue de mesure assignée de l'analyseur est comprise dans les plages de 0 % à 1 % et de 0 % à 100 %, à la pression de référence (généralement proche de la pression atmosphérique).

Seuls quelques gaz présentent un phénomène de paramagnétisme significatif (par exemple l’oxygène, l’oxyde nitrique et le dioxyde d’azote) et parmi les gaz l’oxygène a la plus forte susceptibilité paramagnétique (voir Annexe A). Cette propriété particulière de l'oxygène a permis de concevoir des analyseurs capables d'effectuer des mesurages très spécifiques dans la plupart des applications industrielles et médicales, par exemple lorsqu'il peut exister une quantité importante d’hydrocarbures ou d’humidité résiduels.

Plusieurs techniques différentes de mesure de l'oxygène par sa propriété paramagnétique sont décrites. Les trois principales méthodes, utilisées commercialement depuis des années, ont évolué au fil du temps.

Ces trois méthodes sont les suivantes:

- équilibrage automatique à méthode de zéro;
- vent thermomagnétique ou magnétique;
- pression différentielle ou méthode de Quincke.

Toutes ces méthodes exigent que le gaz échantillon soit propre et sans condensation; cependant, certaines versions fonctionnent à des températures élevées, afin de pouvoir analyser les échantillons qui sont susceptibles de se condenser à des températures inférieures. Cette exigence implique qu'il est souvent nécessaire d’équiper les analyseurs d'un système d'échantillonnage afin de conditionner l'échantillon avant le mesurage.

ANALYSEURS DE GAZ –
EXPRESSION DES PERFORMANCES –

Partie 3: Analyseurs d'oxygène paramagnétiques

1 Domaine d'application

La présente partie de l'IEC 61207 traite des trois principales méthodes de mesure de l'oxygène par sa propriété paramagnétique présentées dans l'introduction. Elle porte sur des unités auxiliaires essentielles et concerne les analyseurs installés à l'intérieur comme à l'extérieur.

Les applications présentant un risque particulier du point de vue de la sécurité peuvent nécessiter des exigences supplémentaires quant aux spécifications du système et de l'analyseur qui ne sont pas traitées dans la présente norme.

La présente norme a pour objet

- de spécifier la terminologie et les définitions relatives aux performances fonctionnelles des analyseurs de gaz paramagnétiques utilisés pour le mesurage de l'oxygène dans un gaz source;
- d'unifier les méthodes utilisées en fournissant et en vérifiant les indications relatives aux performances fonctionnelles de ces analyseurs;
- de spécifier les essais à effectuer pour déterminer les performances fonctionnelles et la manière de réaliser ces essais;
- fournir des documents de base appuyant l'application des normes de gestion de la qualité reconnues sur le plan international.

2 Références normatives

Les documents suivants sont cités dans le texte de sorte qu'ils constituent, pour tout ou partie de leur contenu, des exigences du présent document. Pour les références datées, seule l'édition citée s'applique. Pour les références non datées, la dernière édition du document de référence s'applique (y compris les éventuels amendements).

IEC 61207-1, *Expression des performances des analyseurs de gaz – Partie 1: Généralités*

3 Termes et définitions

Pour les besoins du présent document, les termes et définitions suivants s'appliquent.

NOTE Bien que les unités cgs (centimètre-gramme-seconde) aient été utilisées dans la présente norme, les unités SI (Système international) telles que définies dans l'IUPAC [1][1] peuvent aussi être utilisées.

L'ISO et l'IEC tiennent à jour des bases de données terminologiques destinées à être utilisées en normalisation, consultables aux adresses suivantes:

- IEC Electropedia: disponible à l'adresse http://www.electropedia.org/
- ISO Online browsing platform: disponible à l'adresse http://www.iso.org/obp

---

[1] Les chiffres entre crochets se réfèrent à la Bibliographie.

3.1
susceptibilité magnétique

mesure (X) de la variation de l'intensité du champ magnétique H dans une portion d'espace contenant du vide lorsque ce vide a été remplacé par la substance en essai exprimée par:

$$X = \frac{H^1 - H}{H}$$

où

H est l'intensité du champ magnétique dans le vide

H^1 est l'intensité du champ magnétique dans la substance en essai

Note 1 à l'article: $H^1 - H$ est aussi connue sous le nom de magnétisation MV (dipôle magnétique par unité de volume) et désigne donc également la susceptibilité magnétique volumique.

3.2
paramagnétisme

propriété des substances qui provoquent une augmentation de l'intensité du champ magnétique ($X > 0$)

3.3
diamagnétisme

propriété des substances qui provoquent une diminution de l'intensité du champ magnétique ($X < 0$ car $H^1 < H$)

3.4
susceptibilité magnétique spécifique

rapport de la susceptibilité magnétique à la masse, déterminé comme suit:

$$X_\text{s} = \frac{X}{D}$$

où

D est la densité de la substance considérée, exprimée en $\text{g}\cdot\text{cm}^{-3}$, à 273,15 K, 101,3 kPa.

Note 1 à l'article: L'unité de mesure de X_s est donc le $\text{cm}^3\cdot\text{g}^{-1}$. Elle est également connue sous le nom de susceptibilité magnétique de masse.

3.5
susceptibilité magnétique molaire

X_m

produit de la susceptibilité magnétique spécifique par la masse molaire (M) de la substance considérée:

$$X_\text{m} = X_\text{s} \cdot M$$

où

M est exprimée en g par mole ($\text{g}\cdot\text{mol}^{-1}$) (pour l'oxygène, M = 31,998 8)

Note 1 à l'article: L'unité de mesure de X_m est donc le $\text{cm}^3\cdot\text{mol}^{-1}$.

Note 2 à l'article: Les électrons déterminent les propriétés magnétiques de la matière de deux manières:

- un électron peut être considéré comme une petite sphère chargée négativement qui tourne sur son axe. Cette charge tournante produit un moment magnétique;
- un électron qui décrit une orbite autour d'un noyau produit également un moment magnétique.

C'est la combinaison du moment cinétique intrinsèque et du moment cinétique orbital des électrons qui régit les propriétés magnétiques d'un atome ou d'un ion.

Dans les matériaux paramagnétiques, la principale contribution au moment magnétique provient des électrons non appairés. Ce sont la configuration des orbites des électrons et l'orientation de leur rotation qui déterminent le paramagnétisme de la molécule d'oxygène et la distingue de la plupart des autres gaz.

Note 3 à l'article: Lorsque des gaz paramagnétiques sont placés dans un champ magnétique extérieur, le flux dans le gaz est plus élevé que ce qu'il serait dans le vide, ce qui fait que les gaz paramagnétiques sont attirés vers les zones où le champ magnétique est le plus fort. À l'opposé, les substances diamagnétiques qui contiennent des dipôles magnétiques qui rejettent certaines lignes de force du champ extérieur sont repoussées par l'application du champ magnétique.

Note 4 à l'article: La susceptibilité magnétique molaire de l'oxygène est inversement proportionnelle à la température absolue. Selon Van Vleck [2], la susceptibilité molaire de l'oxygène peut être déterminée approximativement au moyen de l'Équation (4).

Pour l'oxygène,

$$X_{\mathrm{m}} = \frac{8L \cdot \mu_{\mathrm{B}}^{2}}{3kT} \qquad (4)$$

où

X_{m} est la susceptibilité molaire de l'oxygène, exprimée en $\mathrm{cm}^3 \cdot \mathrm{mol}^{-1}$;

L est la constante d'Avogadro = $6{,}022\,7 \times 10^{23}\ \mathrm{mol}^{-1}$;

μ_{B} est le magnéton de Bohr = $9{,}274 \times 10^{-24} \mathrm{A} \cdot \mathrm{m}^2$;

k est la constante de Boltzmann = $1{,}38 \times 10^{-23} \mathrm{J} \cdot \mathrm{K}^{-1}$;

T est la température, exprimée en K (kelvin).

L'Équation (4) peut être réécrite comme suit:

$$X_{\mathrm{m}} = \frac{1010557}{T} \times 10^{-6} \mathrm{cm}^3.\mathrm{mol}^{-1} \text{ (uniquement pour l'oxygène).}$$

Note 5 à l'article: Une explication complète du paramagnétisme et du diamagnétisme peut être trouvée dans les ouvrages de physique et de chimie minérale. Les explications données dans le présent document sont destinées à fournir aux utilisateurs d'analyseurs d'oxygène paramagnétiques les bases leur permettant de comprendre les grandes lignes de la propriété physique utilisée.

3.6

analyseur à équilibrage automatique à méthode de zéro

analyseur qui utilise, comme principe général de fonctionnement, le déplacement d'un dispositif contenant du vide ou un gaz diamagnétique, dans un volume qui contient le gaz à analyser siège d'un champ magnétique élevé et non uniforme, par le biais de la mesure de l'action de ce champ sur les molécules d'oxygène paramagnétiques

Note 1 à l'article: Voir Figure 1.

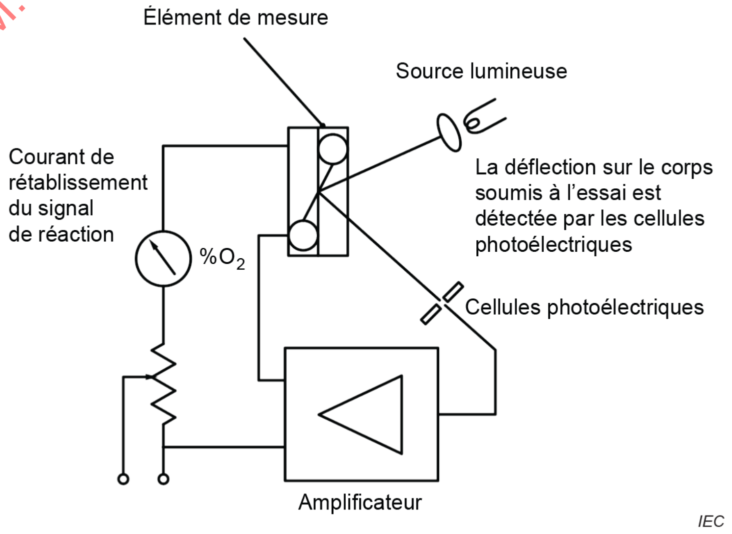


Figure 1 – Système à équilibrage magnétique automatique avec courant de réaction

Note 2 à l'article: L'élément de mesure emploie généralement un haltère en verre dont les sphères contiennent de l'azote, suspendu à une bande de torsion entre des éléments polaires magnétiques ou aimants qui produisent un très fort gradient de champ magnétique autour de l'haltère. L'haltère est dévié lorsque des molécules d'oxygène pénètrent dans l'élément de mesure, une force étant exercée sur l'haltère par les molécules d'oxygène qui sont attirées dans la zone où le champ magnétique est le plus intense. En utilisant un micromesureur à miroir, une bobine de commande magnétique et une électronique adaptée pour générer un signal de réaction qui annule la force de susceptibilité magnétique, il est possible d'obtenir en sortie un signal directement proportionnel à la pression partielle d'oxygène. Le transducteur peut être maintenu à une température constante pour empêcher les variations de susceptibilité magnétique liées à la température de générer des incertitudes. En variante, des capteurs de température incorporés peuvent être utilisés pour assurer la compensation thermique de la valeur de lecture de l'oxygène. De plus, la température élevée présente une utilité dans les applications pour lesquelles l'échantillon n'est pas particulièrement sec. Certains analyseurs sont conçus pour que le capteur fonctionne à une température de plus de 373,15 K (100 °C), afin de faciliter encore les applications pour lesquelles des condensats se formeraient à une température inférieure. L'orientation du capteur paramagnétique peut également avoir une incidence sur l'incertitude de mesure de l'oxygène. Cette incidence peut être corrigée à l'aide d'un algorithme de compensation utilisant, par exemple, un accéléromètre tridimensionnel pour déterminer l'orientation du capteur par rapport à sa position lors de l'étalonnage. Ainsi, la nature mécanique de ce type d'appareils implique une certaine susceptibilité inhérente aux mouvements vibratoires et gyroscopiques qui peut augmenter l'incertitude de mesure.

3.7
analyseur thermomagnétique

3.7.1
analyseur à vent magnétique

analyseur qui utilise la relation entre la susceptibilité magnétique et la température pour générer un débit de gaz induit magnétiquement qui peut être mesuré par un capteur de débit

Note 1 à l'article: Le gaz échantillon passe dans une chambre conçue de sorte que le débit soit divisé en deux à l'entrée.

Note 2 à l'article: Voir Figure 2.

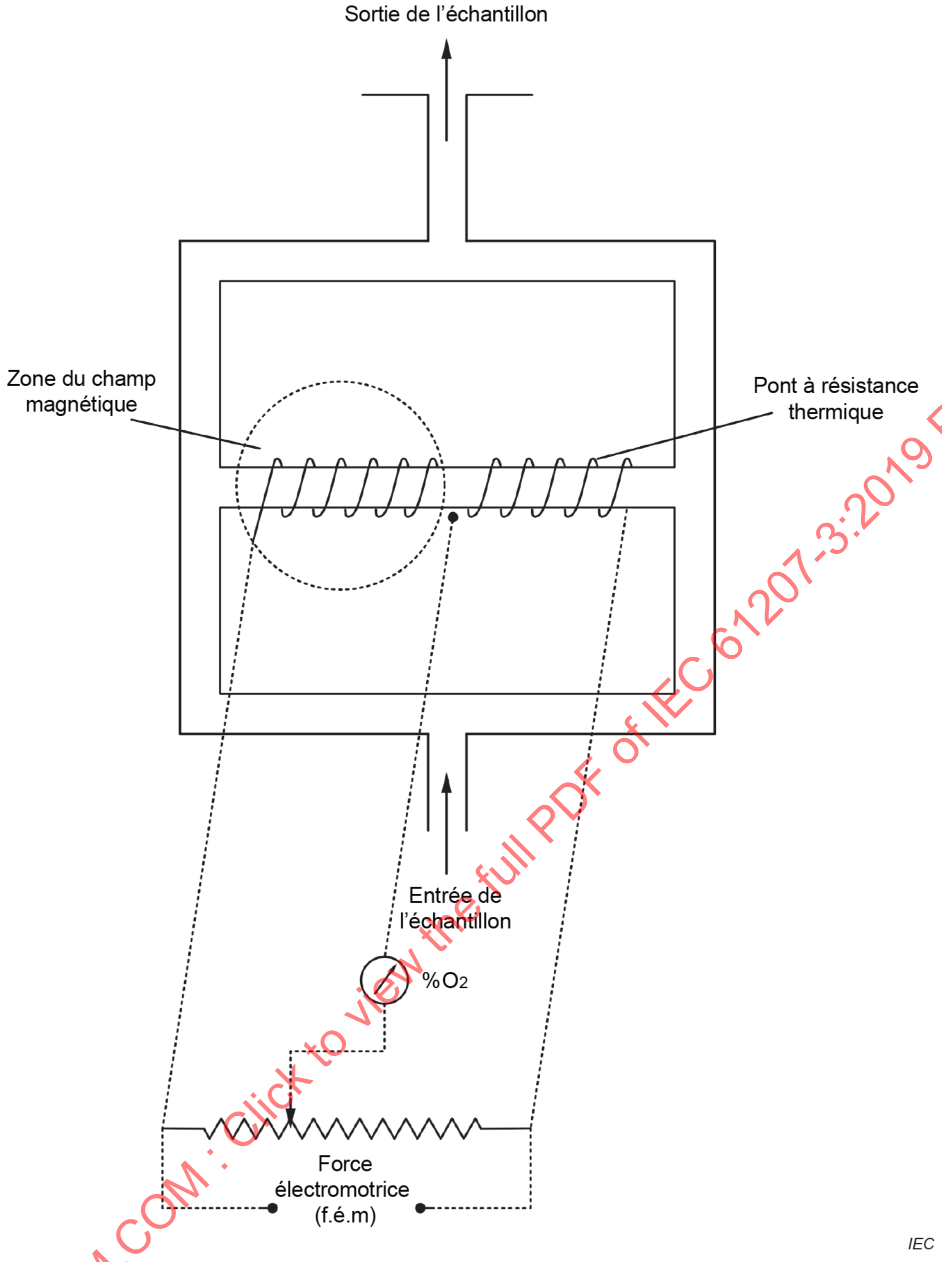


Figure 2 – Capteur d'oxygène thermomagnétique

Note 3 à l'article: Les deux débits se recombinent à la sortie. Le capteur de débit est enroulé autour d'un tube qui relie les deux branches. La moitié du tube de raccordement est placée entre les pôles d'un aimant puissant. Le capteur de débit est constitué de deux bobines de fil électrique chauffées à 353,15 K (80 °C) environ par le passage d'un courant. Les molécules d'oxygène froides sont déviées par le champ magnétique dans le tube central. Leur susceptibilité magnétique diminue au fur et à mesure qu'elles se réchauffent (gradient de température dans le tube) et d'autres molécules d'oxygène froides peuvent pénétrer dans le tube de raccordement. Un flux d'oxygène parcourt le tube dont l'effet est de refroidir la première bobine (celle placée dans la zone de champ magnétique élevé), alors que la température de la deuxième bobine du capteur n'est pas affectée par ce flux transversal. Du fait que les bobines sont constituées de fil thermosensible (par exemple du platine) et connectées ensemble à un pont de Wheatstone, le courant de déséquilibre résultant est une fonction pratiquement proportionnelle de la pression partielle d'oxygène dans le gaz analysé.

Les analyseurs les plus récents utilisent des éléments de mesure plus élaborés, des résistances toroïdales au lieu du capteur de débit à deux bobines, et un système de régulation de température pour réduire le plus possible les changements de température ambiante.

Cette méthode reposant sur le transfert thermique, la conductivité thermique des gaz résiduels influe sur la valeur de lecture de l'oxygène. Il faut donc connaître la composition des gaz résiduels. Dans ce cas également, les analyseurs de gaz plus récents apportent une correction par le biais de dispositifs de compensation supplémentaires.

La sortie des analyseurs thermomagnétiques n'est pas strictement linéaire et il est exigé de procéder à un traitement supplémentaire du signal pour obtenir une sortie linéaire.

3.8
analyseur Quincke

3.8.1
analyseur à pression différentielle

analyseur qui utilise un système de comparateur pneumatique établi à l'aide d'un gaz de référence (tel que l'azote ou l'air) qui s'écoule

Note 1 à l'article: L'élément de mesure est conçu de telle sorte que le débit de gaz de référence soit divisé en deux à l'entrée. Ces deux débits se recombinent en sortie, à l'endroit où le gaz à analyser est également introduit. Un capteur de pression différentielle (ou un capteur de microdébit) est positionné à l'intérieur des deux flots de gaz de référence, de sorte que tout déséquilibre soit détecté. Un aimant est placé à proximité de la sortie du gaz de référence sur une des branches de l'élément de mesure, de sorte que l'oxygène présent dans l'échantillon soit attiré dans la branche en question, ce qui provoque une faible contre-pression détectée par le capteur de pression (voir Figure 3).

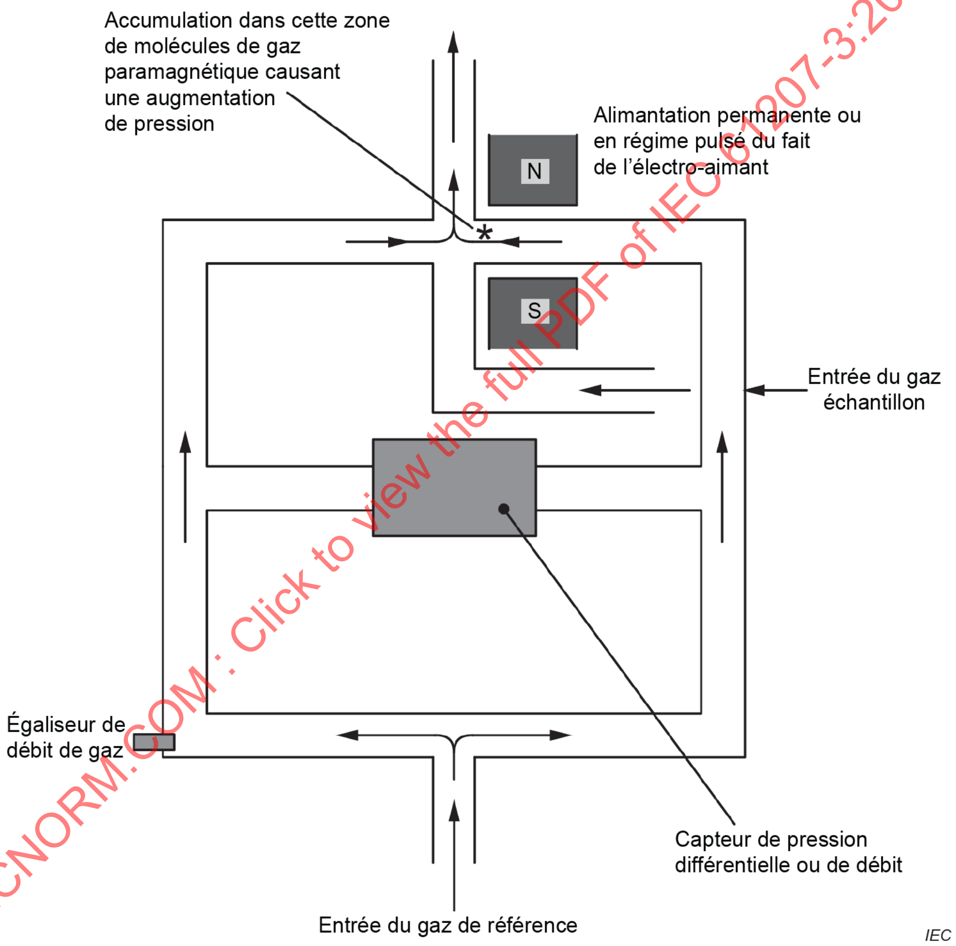


Figure 3 – Capteur d'oxygène à pression différentielle

Note 2 à l'article: Les analyseurs à pression différentielle sont indépendants de la conductivité thermique des gaz résiduels et, comme seul le gaz de référence entre en contact avec le capteur, les problèmes de corrosion sont minimes. Certains instruments utilisent des champs magnétiques en régime pulsé pour améliorer la sensibilité à l'inclinaison (position) et d'autres modèles compensent l'effet des vibrations.

3.9
zone dangereuse

zone dans laquelle une atmosphère explosive gazeuse est présente, ou peut être présente, dans des quantités qui exigent de prendre des mesures spéciales pour la construction, l'installation et l'utilisation des appareils

3.10
appareil auxiliaire essentiel
appareil sans lequel l'analyseur ne peut fonctionner dans le respect des spécifications

EXEMPLE: Systèmes d'étalonnage, systèmes pour gaz de référence, systèmes d'échantillonnage.

3.11
système d'échantillonnage
système d'éléments assemblés sur un panneau ou dans le boîtier d'un analyseur ayant pour but de transporter le gaz échantillon du point d'échantillonnage à l'analyseur et de présenter l'échantillon de manière à pouvoir réaliser des mesurages fiables

Note 1 à l'article: Les composants utilisés peuvent comprendre

- des régulateurs de pression;
- des débitmètres;
- des régulateurs de débit;
- des unités de filtration;
- des pompes;
- des vannes (manuelles et/ou électriques);
- des pièges à condensats ou séparateurs;
- des refroidisseurs;
- des réchauffeurs;
- des unités de séchage;
- des unités de lavage.

Note 2 à l'article: Voir Figure 4 et Figure 5 pour des exemples de systèmes d'échantillonnage types. Les exigences relatives aux systèmes d'échantillonnage sont présentées de manière détaillée dans l'IEC 61115 [3]. Ces composants sont habituellement conçus par l'utilisateur ou, plus souvent, par un fabricant, comme système d'échantillonnage, de sorte que les exigences relatives à l'analyseur définies dans les spécifications se situent à l'intérieur de la plage de fonctionnement assignée. Les exigences de conception du système dépendent donc en grande partie des conditions d'échantillonnage. Les variations de la pression de l'échantillon, de la température, de la charge en poussière et de la pression d'autres gaz et vapeurs influent sur la conception du système d'échantillonnage final.