

Explosive atmospheres —

**Part 29-2: Gas detectors — Selection,
installation, use and maintenance of
detectors for flammable gases and
oxygen**

ICS 13.320; 29.260.20

Licensed Copy: x x, Mott Macdonald, 04/11/2009 08:00, Uncontrolled Copy, (c) BSI

National foreword

This British Standard is the UK implementation of EN 60079-29-2:2007. It is identical to IEC 60079-29-2:2007. It supersedes BS EN 50073:1999, which will be withdrawn on 1 November 2010.

The UK participation in its preparation was entrusted by Technical Committee GEL/31, Equipment for explosive atmospheres, to Subcommittee GEL/31/19, Gas detectors.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a British Standard cannot confer immunity from legal obligations.

This British Standard was published under the authority of the Standards Policy and Strategy Committee on 29 February 2008

© BSI 2008

ISBN 978 0 580 54363 0

Amendments/corrigenda issued since publication

Date	Comments

EUROPEAN STANDARD

EN 60079-29-2

NORME EUROPÉENNE

EUROPÄISCHE NORM

November 2007

ICS 29.260.20

Supersedes EN 50073:1999
Incorporates Corrigendum December 2007

English version

**Explosive atmospheres -
Part 29-2: Gas detectors -
Selection, installation, use and maintenance of detectors
for flammable gases and oxygen
(IEC 60079-29-2:2007)**

Atmosphères explosives -
Partie 29-2: Détecteurs de gaz -
Sélection, installation, utilisation
et maintenance des détecteurs
de gaz inflammables et d'oxygène
(CEI 60079-29-2:2007)

Explosionsfähige Atmosphäre -
Teil 29-2: Gasmessgeräte -
Auswahl, Installation, Einsatz und
Wartung von Geräten für die Messung von
brennbaren Gasen und Sauerstoff
(IEC 60079-29-2:2007)

This European Standard was approved by CENELEC on 2007-11-01. CENELEC members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration.

Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Central Secretariat or to any CENELEC member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CENELEC member into its own language and notified to the Central Secretariat has the same status as the official versions.

CENELEC members are the national electrotechnical committees of Austria, Belgium, Bulgaria, Cyprus, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and the United Kingdom.

CENELEC

European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

Central Secretariat: rue de Stassart 35, B - 1050 Brussels

Foreword

The text of document 31/696/FDIS, future edition 1 of IEC 60079-29-2, prepared by IEC TC 31, Equipment for explosive atmospheres, was submitted to the IEC-CENELEC parallel vote and was approved by CENELEC as EN 60079-29-2 on 2007-11-01.

This European Standard supersedes EN 50073:1999.

This part of EN 60079-29 is to be used in conjunction with the following standards:

- EN 60079-0, Electrical apparatus for explosive gas atmospheres – Part 0: General requirements
- EN 60079-29-1, Explosive atmospheres – Part 29-1: Gas detectors – Performance requirements of detectors for flammable gases.

The following dates were fixed:

- latest date by which the EN has to be implemented
at national level by publication of an identical
national standard or by endorsement (dop) 2008-11-01
- latest date by which the national standards conflicting
with the EN have to be withdrawn (dow) 2010-11-01

Annex ZA has been added by CENELEC.

The contents of the corrigendum of December 2007 have been included in this copy.

Endorsement notice

The text of the International Standard IEC 60079-29-2:2007 was approved by CENELEC as a European Standard without any modification.

CONTENTS

INTRODUCTION	7
1 Scope	9
2 Normative references	10
3 Terms and definitions	10
4 Basic information on the properties, behaviour, and detection of gases and vapours	16
4.1 Detecting gases and vapours – General	16
4.1.1 Safety when monitoring for flammable gases where personnel could be present	17
4.2 Some common properties of gases and vapours	18
4.3 The differences between detecting gases and vapours	19
4.3.1 Detection of gases	19
4.3.2 Detection of vapours	21
4.4 Oxygen deficiency	24
4.4.1 Chemical reaction of oxygen, with solid products	24
4.4.2 Chemical reaction of oxygen, with gaseous products	24
4.4.3 Dilution of the air by displacement by some other gas or vapour	25
5 Measuring principles	26
5.1 Catalytic sensors	27
5.1.1 Common applications	27
5.1.2 Limitations	27
5.1.3 Interferences	28
5.1.4 Poisoning	28
5.2 Thermal conductivity sensors	29
5.2.1 Common applications	29
5.2.2 Limitations	29
5.2.3 Interferences	30
5.2.4 Poisoning	30
5.3 Infrared sensors	30
5.3.1 Common applications	31
5.3.2 Limitations	31
5.3.3 Interferences	31
5.3.4 Poisoning	31
5.4 Semiconductor sensors	32
5.4.1 Common applications	32
5.4.2 Limitations	32
5.4.3 Interferences	32
5.4.4 Poisoning	33
5.5 Electrochemical sensors	33
5.5.1 Common applications	33
5.5.2 Limitations	33
5.5.3 Interferences	34
5.5.4 Poisoning	34
5.6 Flame ionization detectors (FID)	35
5.6.1 Common applications	35
5.6.2 Limitations	35

5.6.3	Interferences	35
5.6.4	Poisoning	36
5.7	Flame temperature analysers (FTA)	36
5.7.1	Common applications	36
5.7.2	Limitations	36
5.7.3	Interferences	36
5.7.4	Poisoning	36
5.8	Photo Ionisation Detector (PID)	36
5.8.1	Common applications	37
5.8.2	Limitations	37
5.8.3	Interferences	37
5.8.4	Poisoning	37
5.9	Paramagnetic oxygen detector	38
5.9.1	Common applications	38
5.9.2	Limitations	38
5.9.3	Interference	38
5.9.4	Poisoning	38
6	Selection of apparatus	38
6.1	General	39
6.2	Selection criteria	39
6.2.1	General criteria	39
6.2.2	Gases to be detected by the apparatus	40
6.2.3	Intended application of the apparatus	42
6.2.4	Transportable apparatus	43
6.3	Miscellaneous factors affecting selection of apparatus	44
6.3.1	Electromagnetic immunity	44
6.3.2	Intended zone(s) of use	44
7	Behaviour of gas releases	44
7.1	Nature of a release	44
7.1.1	General	44
7.1.2	Release rate of gas or vapour	44
7.1.3	Flammable limits	45
7.1.4	Ventilation	45
7.1.5	Relative density of the released gas or vapour	46
7.1.6	Temperature and/or pressure	46
7.1.7	Other parameters to be considered	46
7.1.8	Outdoor sites and open structures	46
7.2	Buildings and enclosures	47
7.2.1	General	47
7.3	Unventilated buildings and enclosures	47
7.4	Ventilated buildings and enclosures	47
7.5	Natural ventilation	47
7.5.1	Mechanical ventilation	48
7.5.2	Environmental considerations	48
8	Design and installation of fixed gas detection systems	48
8.1	Basic considerations for the installation of fixed systems	49
8.2	Location of detection points	50

8.2.1	General site considerations.....	50
8.2.2	Environmental conditions	51
8.3	Access for calibration and maintenance	53
8.4	Additional considerations for sample lines.....	54
8.5	Summary of considerations for the location of sensors or sampling points	54
8.6	Installation of sensors.....	55
8.7	Integrity and safety of fixed systems	56
8.7.1	General	56
8.7.2	Redundancy in fixed systems	56
8.7.3	Protection against loss of main power supply	56
8.8	Timing of installation during construction operations	57
8.9	Commissioning.....	57
8.9.1	Inspection.....	57
8.9.2	Initial gas calibration	57
8.9.3	Adjustment of alarm set points	58
8.10	Operating instructions, plans and records	58
9	Use of portable and transportable flammable gas detection apparatus	59
9.1	General.....	59
9.2	Initial and periodic check procedures for portable and transportable instrumentation.....	60
9.2.1	Inspection and field-check (response check)	60
9.2.2	Routine checks and recalibration	61
9.2.3	Maintenance and recalibration	62
9.3	Guidance on the use of portable and transportable apparatus	63
9.3.1	Electrical safety in hazardous atmospheres.....	63
9.3.2	Safety of personnel.....	63
9.3.3	Spot tests and sampling	63
9.3.4	Sampling above liquids	64
9.3.5	Avoidance of condensation	64
9.3.6	Poisoning of sensors.....	64
9.3.7	Changes of temperature.....	64
9.3.8	Accidental damage	65
9.3.9	Minimalist operation, the “Read and run” concept.....	65
10	Training of operational personnel.....	65
10.1	General.....	65
10.2	General training – Basic limitations and safety	66
10.3	Operator training	67
10.4	Maintenance training	67
11	Maintenance, routine procedures and general administrative control	67
11.1	General.....	67
11.2	Operational checks.....	69
11.2.1	Fixed systems.....	69
11.2.2	Portable and transportable gas detection apparatus	70
11.3	Maintenance.....	70
11.3.1	General	70
11.3.2	Fixed apparatus.....	71
11.3.3	Portable and transportable gas detection apparatus	71
11.3.4	Off-site maintenance, general	71

11.3.5 Maintenance procedures	71
11.4 Sensors.....	72
11.4.1 General	72
11.4.2 Flame arrestor	72
11.5 Flow systems	72
11.5.1 General	72
11.5.2 Filters, traps and flame arrestors.....	72
11.5.3 Flow system and sample chamber.....	72
11.5.4 Flow connections	72
11.5.5 Moving parts	72
11.5.6 Automatic sample-draw systems	73
11.5.7 Trouble signals	73
11.6 Readout devices.....	73
11.6.1 General	73
11.6.2 Other readouts.....	73
11.7 Alarms	73
11.8 Workshop calibration test and equipment.....	73
11.8.1 Calibration kits and test equipment	73
11.8.2 Conduct of workshop calibration testing	74
Annex A (normative) Measuring principles	76
Annex B (informative) Environmental parameters	96
Annex C (informative) Typical environmental and application check-list for flammable gas detectors.....	97
Annex D (informative) Typical instrument maintenance record for flammable gas detectors	99
Annex ZA (normative) Normative references to international publications with their corresponding European publications	102
Bibliography	101
Table 1 – Overview of gas detection apparatus with different measuring principles	26
Table A.1 – Overview of gas detection apparatus with different measuring principles.....	76
Table B.1 – Environmental parameters.....	96

INTRODUCTION

Flammable gas detection apparatus may be used whenever there is the possibility of a hazard to life or property caused by the accumulation of a flammable gas-air mixture. Such apparatus can provide a means of reducing the hazard by detecting the presence of a flammable gas and issuing suitable audible or visual warnings. Gas detectors may also be used to initiate precautionary steps (for example plant shutdown, evacuation, and operation of fire extinguishing procedures).

Apparatus may be used to monitor a gas atmosphere below the lower flammable limit in circumstances where accumulation of gas may result in a concentration of the gas/air mixture to potentially explosive levels. Performance requirements for gas detecting apparatus for such purposes are set out in IEC 60079-29-1.

However performance capability alone cannot ensure that the use of such apparatus will properly safeguard life or property where flammable gases may be present. The level of safety obtained depends heavily upon correct selection, installation, calibration and periodic maintenance of the apparatus, combined with knowledge of the limitations of the detection technique required. This cannot be achieved without responsible informed management.

An additional hazard to life is the toxicity of some gases and of the vapours of all liquids except water. It is not generally appreciated that all flammable vapours are potentially toxic at concentration levels which are very small fractions of their respective lower flammable limits. Apparatus covered by the IEC 60079-29-1 is not specifically intended for toxic protection, and additional personal protection precautions will normally be needed where personnel could be exposed to toxic vapours.

Portable apparatus covered by the IEC 60079-29-1 and the IEC 60079-29-2 commonly have additional detectors for specific toxic gases and also for oxygen deficiency. Users are cautioned that even mild oxygen deficiency may be due to toxic concentrations of some other gas or vapour, which may not be detectable or adequately detected by the apparatus in use.

General requirements for the handbook or manual of any particular flammable gas detection apparatus are specified in IEC 60079-29-1. This standard provides some necessary background knowledge on the points mentioned above.

This standard has been specifically written to cover all the functions necessary to go from the need for gas detection all the way through ongoing maintenance of a successful gas detection operation. Different clauses are appropriate for different tasks within this range of operations. Each clause has been written as stand-alone as far as practicable. This meant that some information is repeated in different clauses but with a different emphasis.

The following table gives a broad suggestion as to the most relevant clauses to the typically tasks to be performed.

	Definitions	Basic information properties of gas and vapours	Measuring principles	Selection of apparatus	Behaviour of gas releases	Design and installation of fixed gas detection systems	Use of portable and transportable flammable gas detection apparatus	Training of operational personnel	Maintenance, routines procedures General administrative control	Measuring principles (full detail) (normative)	Environmental parameters (informative)
Function (Clause)	3	4	5	6	7	8	9	10	11	Annex A	Annex B
Authorities	+	+++	+++	+	+	-	-	-	+	-	-
General management	+	+++	+++	+	+	-	-	+	+	-	+
Selection	+++	+++	+	+++	+++	+	++	-	+	+++	+++
Design engineering / management	+++	+++	+	+++	+++	+++	-	-	-	+++	+++
Installation engineering / management	+++	+++	+	++	+++	+++	-	-	-	+++	+++
Installation, technical	++	+++	++	++	++	++	-	-	-	+	++
Commissioning	+++	+++	++	+	++	+++	-	++	+	-	-
Operations management	++	+++	++	+	+	++	++	+++	+++	+	+++
Operation training	+++	+++	+	+	+	+++	+++	+++	+++	+++	+++
Servicing / Calibration	+++	+++	-	-	-	++	++	+	+++	++	++
Repair	++	+++	++	-	-	+	+	+	+++	++	-
“+++” Essential “++” Advisable “+” Useful “-” Not applicable NOTE It should be noted that Clause 5 is a simplified version of Annex A.											

This standard makes recommendations how to establish maintenance and calibration intervals. In certain countries there are general or industry-specific regulations that are mandatory and those shall be followed as a minimum requirement.

EXPLOSIVE ATMOSPHERES –

Part 29-2: Gas detectors –

Selection, installation, use and maintenance of detectors for flammable gases and oxygen

1 Scope

This part of IEC 60079-29 gives guidance on, and recommended practice for, the selection, installation, safe use and maintenance of electrically operated group II apparatus intended for use in industrial and commercial safety applications for the detection and measurement of flammable gases complying with the requirements of IEC 60079-29-1.

This standard is applicable for oxygen measurement for the purpose of inertisation where explosion protection is provided by the exclusion of oxygen instead of measuring the combustible gases or vapours present.

This standard is a compilation of practical knowledge to assist the user, and applies to apparatus, instruments and systems that indicate the presence of a flammable or potentially explosive mixture of gas or vapour with air by using an electrical signal from a gas sensor to produce a meter reading, to activate a visual or audible pre-set alarm or other device, or any combination of these.

Such apparatus may be used as a means of reducing the risk whenever there is the possibility of a risk to life or property specifically due to the accumulation of a combustible gas-air mixture, by providing such warnings. It may also be used to initiate specific safety precautions (e.g. plant shutdown, evacuation, fire extinguishing procedures).

This standard is applicable to all new permanent installations and, where reasonably practicable, to existing permanent installations. It is also applicable to temporary installations, whether new or existing.

Similarly it is applicable to the safe use of portable or transportable apparatus, irrespective of the age or complexity of such apparatus. Since much modern apparatus of this type also includes oxygen deficiency detection and/or specific toxic gas sensors, some additional guidance is given for these topics.

NOTE When in classified areas, the apparatus should be so installed and used that it is not capable of itself igniting a combustible gas-air mixture. It should therefore comply with the requirements of IEC 60079-10.

For the purposes of this standard, except where specifically stated otherwise, flammable gases shall include flammable vapours.

This standard applies only to group II apparatus (i.e. apparatus intended for use in industrial and commercial safety applications, involving areas classified in accordance with IEC 60079-10).

For the purposes of this standard, apparatus includes

- a) fixed apparatus;
- b) transportable apparatus; and
- c) portable apparatus.

This standard is not intended to cover, but may provide useful information, for the following:

- a) apparatus intended only for the detection of non-flammable toxic gases;
- b) apparatus of laboratory or scientific type intended only for analysis or measurement purposes;
- c) apparatus intended for underground mining applications (group I apparatus);
- d) apparatus intended only for process control applications;
- e) apparatus intended for applications in explosives processing and manufacture;
- f) apparatus intended for the detection of a potentially flammable atmosphere resulting from dust or mist in air;
- g) open path apparatus not used for point measurement.

2 Normative references

The following referenced documents are indispensable for the application 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 60050-426, *International Electrotechnical Vocabulary (IEV) – Chapter 426: Electrical apparatus for explosive atmospheres*

IEC 60079-0, *Electrical apparatus for explosive gas atmospheres – Part 0: General requirements*

IEC 60079-10, *Electrical apparatus for explosive gas atmospheres – Part 10: Classification of hazardous areas*

IEC 60079-20, *Electrical apparatus for explosive gas atmospheres – Part 20: Data for flammable gases and vapours, relating to the use of electrical apparatus*

IEC 60079-29-1, *Explosive atmosphere – Part 29-1: Gas detectors – Performance requirements*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050(426) and IEC 60079-0, as well as the following apply. Also, since this is intended as a stand-alone standard, certain definitions within IEC 60079-29-1 are repeated below for the convenience of the reader.

3.1

alarm setpoint

fixed or adjustable setting of the apparatus that is intended to pre-set the level of concentration at which the apparatus will automatically initiate an indication, alarm or other output function

3.2

ambient air

the normal atmosphere surrounding the apparatus

3.3

aspirated apparatus

apparatus that samples the gas by drawing it to the gas sensor – for example by means of a hand-operated or electric pump

3.4

catalytic sensor

sensor, the operation of which depends upon the oxidation of gases on an electrically heated catalytic element

3.5

clean air

air that is free of flammable gases and interfering or contaminating substances

3.6

concentration

the amount of the gas or vapour of interest in a specified amount of the background gas or air, expressed in suitable units

NOTE Typical units include volume fraction (v/v) (see 3.57); molar (moles per mole – m/m); percentage of the LFL of a particular substance; parts per million by volume (ppm); parts per billion by volume (ppb).

3.7

continuous duty apparatus

gas detecting apparatus that is powered for long periods of time, but may have either continuous or intermittent sensing

3.8

continuous or quasi-continuous sensing

mode of operation in which power is applied continuously to the sensing element and readings are taken continuously or at regular and frequent intervals

3.9

diffusion apparatus

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

3.10

dose

the total amount of substance absorbed or trapped, proportional to the concentration and the duration of exposure

3.11

drift

variation in the apparatus indication with time at any fixed gas volume fraction (including clean air) under constant ambient conditions

3.12

electrochemical sensor

sensor, the operation of which depends upon changes of the electrical parameters of electrodes placed in an electrolyte due to redox reactions of the gas on the surface of the electrodes

3.13

explosion protected apparatus

apparatus incorporating a type of protection covered by the IEC 60079 series of standards

3.14

explosive gas atmosphere

mixture with air, under normal atmospheric conditions, of flammable substances in the form of gas or vapour, in which, after ignition, permits self-sustaining flame propagation

NOTE 1 This definition specifically excludes dusts and fibres in suspension in air. Mists are not covered by this standard.

NOTE 2 Although a mixture that has a concentration above the upper flammable limit (see 3.54) is not an explosive atmosphere, in certain cases for area classification purposes, it is advisable to consider it as an explosive gas atmosphere.

NOTE 3 Normal atmospheric conditions include variations above and below reference levels of 101,3 kPa and 20 °C provided the variations have a negligible effect on the explosive properties of the flammable materials.

3.15

explosive range

range of gas or vapour mixtures with air, with concentrations between the lower and upper explosive (flammable) limits

3.16

field check with gas (response check)

application of test gas to the sensor to check the response signal or the generation of an alarm, without adjustments of zero, sensitivity, or alarm level

3.17

firedamp

flammable gas, consisting mainly of methane, found naturally in mines

3.18

fixed apparatus

apparatus that is intended to have all its parts permanently installed

3.19

flame ionisation detector

FID

sensor, the operation of which depends upon the ionization of the gas being detected in a hydrogen flame

3.20

flame temperature analyser

FTA

sensor, the operation of which depends upon the change of temperature of a flame by the gas being detected

3.21

flammable gas

gas or vapour which, when mixed with air in a certain proportion, will form an explosive atmosphere

NOTE For the purposes of this standard, the term "flammable gas" includes flammable vapours.

3.22

flashpoint

lowest liquid temperature at which, under certain standardized conditions, a liquid gives off vapours in a quantity such as to be capable of forming an ignitable vapour/air mixture

3.23

group II apparatus

electrical apparatus for places with a potentially explosive atmosphere, other than mines susceptible to firedamp

3.24

infrared absorption sensor

sensor, the operation of which depends upon the absorption of infrared radiation by the gas being detected

3.25

initial calibration

the first calibration for a specific substance, measuring range and application carried out by the manufacturer before delivery, or on site, before starting the operation

3.26

intermittent sensing

mode of operation in which the power or flow to the sensor is applied intermittently according to a predetermined cycle and readings taken at the predetermined cycle

3.27

lower flammable limit

LFL

volume fraction of flammable gas or vapour in air below which an explosive gas atmosphere does not form, expressed as a percentage (see IEC 60079-20)

NOTE This is also known as lower explosive limit (LEL).

3.28

open path infrared sensor

sensor capable of detecting gas at any location along an open path traversed by an infrared beam

3.29

paramagnetic oxygen detector

sensor, the operation of which depends upon the magnetic properties of the gas being detected

3.30

photo ionisation detector

PID

sensor, the operation of which is based on the ionisation of gaseous compounds by ultraviolet (UV) radiation

3.31

poisons (of sensors)

substances which lead to temporary or permanent loss of sensitivity of the sensors

3.32

portable apparatus

spot reading or continuous duty apparatus that has been designed to be readily carried from place to place and to be used while it is being carried. A portable apparatus is battery powered and includes, but is not limited to

- a) a hand-held apparatus, typically less than 1 kg, which requires use of only one hand to operate;
- b) personal monitors, similar in size and mass to the hand-held apparatus, that are continuously operating (but not necessarily continuously sensing) while they are attached to the user; and
- c) larger apparatus that can be operated by the user while it is carried either by hand, by a shoulder strap or by a carrying harness; which may or may not have a hand directed probe

3.33**potentially explosive atmosphere**

atmosphere that could become explosive (the danger is a potential one)

NOTE This would include an atmosphere with gas concentration currently above UFL (upper flammable limit), where dilution with air would render it explosive.

3.34**recalibration**

calibrations carried out periodically to check and adjust the zero signal and the sensitivity of the sensor with a known calibration gas mixture without any changing of the parameters, type of gas, measuring range, specific application, which have been established by the initial calibration

3.35**recovery time**

the time interval between the time when an instantaneous decrease in gas concentration is produced at the sensor input and the time when the response reaches a stated indication

3.36**relative density**

density of gas or vapour relative to the density of air at the same pressure and at the same temperature (air is equal to 1,0)

3.37**release rate**

quantity of flammable gas or vapour emitted per unit time from the source of release which itself could be a liquid surface

3.38**remote sensor**

sensor that is not integral with the main body of the apparatus

3.39**response check**

see "field check with gas"

3.40**response time**

time interval, with the apparatus in a warmed-up condition, between the time when an instantaneous change between clean air and the standard test gas, or vice versa, is produced at the apparatus inlet, and the time when the response reaches a stated percentage (x) of the stabilised signal on the standard test gas

3.41**sample line**

a means by which the gas being sampled is conveyed to the sensor including accessories (e.g. filter, water trap)

3.42**sampling probe**

separate sample line which is attached to the apparatus as required, that may or may not be supplied with the apparatus. It is usually short (e.g. in the order of 1 m) and rigid (although it may be telescopic), but it may be connected by a flexible tube to the apparatus

3.43**selectivity**

response of the apparatus to the gas of interest compared with the response to other gases

NOTE If there is high selectivity to the target gas, the results will be less ambiguous and the cross sensitivity to other gases will be low.

3.44

semiconductor sensor

sensor, the operation of which depends upon changes of the electrical conductance of a semi-conductor due to chemisorption of the gas being detected at its surface

3.45

sensitivity

the ratio of change produced in the apparatus by a known concentration of gas or vapour

NOTE 1 Depending on context, this can refer to the minimum change in concentration of gas or vapour that the apparatus will detect.

NOTE 2 High sensitivity implies that low concentrations can be measured.

3.46

sensor

assembly in which the sensing element is housed that may also contain associated circuit components

3.47

sensing element

that part of a sensor that reacts in the presence of a flammable gas mixture to produce some physical or chemical change that can be used to activate a measuring or alarm function, or both

3.48

single point sensor

sensor capable of detecting gas at a single point location

3.49

source of release

point or location from which a flammable gas, vapour or liquid may be released into the atmosphere such that an explosive gas atmosphere could be formed

[IEV 426-03-06, modified]

3.50

span

upscale reading on the normal test gas of the apparatus

3.51

spot reading apparatus

apparatus intended to be used for short, intermittent or irregular periods of time as required (typically 5 min or less)

3.52

thermal conductivity sensor

sensor, the operation of which depends upon the change of heat lost by conduction of an electrically heated element located in the gas to be measured, compared with that of a similar element located in a reference gas cell

3.53

transportable apparatus

apparatus not intended to be portable, but which can be readily moved from one place to another

3.54**upper flammable limit****UFL**

volume fraction of flammable gas or vapour in air above which an explosive gas atmosphere does not form, expressed as a percentage (see IEC 60079-20)

NOTE This is also known as upper explosive limit (UEL).

3.55**vapour**

gaseous state of a substance that can reach equilibrium with its liquid or solid state in the temperature and pressure range of interest

NOTE This is a simplification of the scientific definition, for the purposes of this standard, and merely requires that the substance is below its boiling point or sublimation point at the ambient temperature and pressure.

3.56**ventilation**

movements of air and replacement with fresh air due to the effects of wind, temperature gradients or artificial means (for example fans or extractors)

3.57**volume fraction****v/v**

ratio of the volume of a component gas to the volume of the gas mixture under specified conditions of temperature and pressure

NOTE This is also known as volume ratio.

3.58**zero gas**

gas recommended by the manufacturer which is free of flammable gases, and interfering and contaminating substances, the purpose of which is calibration/adjustment of the apparatus zero

4 Basic information on the properties, behaviour, and detection of gases and vapours

For this clause, a distinction is drawn between gases, which remain gaseous at typical ambient pressures and temperatures, and vapours where liquid can also exist at any relevant pressure or temperature.

4.1 Detecting gases and vapours – General

Effective operation of flammable gas detection apparatus depends not only on its performance but also on its correct usage.

Apparatus capability, and its suitability for the intended application and the user's knowledge of its limitations, both generic relating to sensor technology, and individual relating to its other design features, cannot alone ensure that its use will properly safeguard personnel, areas, or locations where flammable gases or vapours may be or are present. The level of safety obtained also depends upon the user having a basic knowledge of gas and vapour properties and phenomena.

This knowledge should enable the user to determine whether the gases are heavier or lighter than air, and whether the vapours are heavier than air or of similar density, and therefore where they may accumulate. If the direction and velocity of air movement is known, it can be seen how they may propagate. Also there may be physical or chemical reasons imposing limitations on a particular application, such as calibration considerations.

Consideration has to be given not only to those gases and vapours that are required to be detected, but also to those gases and vapours that are not required to be detected, but may also be present.

The effects of humidity and temperature variations may need to be evaluated, particularly when sampling lines are used, and, more importantly, if vapours other than water are involved.

Small environmental changes, such as a rise or fall in temperature, which may be ignored for most purposes, can significantly modify conditions, particularly if liquids are present and produce increased amounts of vapours, or if vapours condense as fogs or inside the apparatus itself.

Failure to take these properties of gases and vapours into account at any of the stages of selection, installation, commissioning, training, operation and on-going maintenance of even the simplest of apparatus can result in the production of erroneous readings. These in turn can lead, on one hand to false alarms or incorrect action, and on the other hand failure to alarm or failure to take any appropriate action. Such factors can unnecessarily endanger lives and property.

Some gases or vapours can cause corrosion or other deterioration to certain types of sensors. Some types of sensors have specific lifetimes. The sensitivity can change over time. This applies to certain types of sensors for toxic gases and oxygen deficiency as well as for flammable gases and vapours. This is the major reason for requiring frequent response checking. It is usually done using a test gas or calibration gas applied in a specified way. The correct test/calibration equipment for one type of gas detection apparatus may not be appropriate to another type, and some training will usually be needed.

4.1.1 Safety when monitoring for flammable gases where personnel could be present

When entering the potentially hazardous area frequently observe the readings on the apparatus. Personnel could be entering an already dangerous situation and may need expedient warning.

The apparatus will only give a reading for the location where the reading is being taken, or the location of the end of the sampling line if a sampling line is being used. A hazardous atmosphere may be building up a few metres from the sampling point. Therefore, many gas tests must be done all around the intended area of work to ensure that no pockets of hazardous gas or vapour are present in the work area.

If vapours are likely to be present, some of the tests should be done one or two centimetres from the floor. This might detect a small problem (e.g. a minor liquid leak) at an early stage. All nearby low spots should be tested.

The readings are only valid for the time they are taken. Circumstances change. Frequent readings are recommended, particularly if vapours (see 4.3.2) could be involved and the temperature is rising.

Where a wide range of gases and vapours could be encountered in the work area there will be a range of potential sensitivities. A low 'alarm point' or 'action point' will therefore be required.

If there is a chance of sensor 'poisons' (such as silicones, leaded petrol, acids, etc) being present, the sensitivity of an apparatus, using catalytic combustion or semiconductor sensors, should be checked at frequent intervals.

While the atmosphere is being monitored for flammable properties of gases and vapours, consideration should also be given to the fact that many of these, including all vapours except water, are also toxic to personnel. Additional detectors for the specific gases and vapours and additional precautions may be needed.

If a flammable gas or vapour detection apparatus is also equipped with high sensitivity sensors for specific toxic gases it should be realized that they may only detect these specific gases. They will not usually detect other toxic materials.

Closely allied to flammable gas monitoring is monitoring for oxygen deficiency. Frequently this feature is added to the apparatus. There are several possible reasons for an oxygen deficiency. Some of them are due to situations where a toxic substance is part of the cause of the deficiency, and these are of far greater concern. Again, additional detectors and precautions may be needed.

Therefore, when about to work in a hazardous area, it is advisable to specifically check on the potential toxicity of the atmosphere with the plant safety officer, industrial hygienist, or equivalent.

NOTE Different countries have different systems, and may use different values, for describing maximum safe levels of potentially toxic substances. For typical details, consult the USA's ACGIH book of TLV's (Threshold Limiting Values) and BEIs, or the European Commission for the Investigation of Health Hazards of Chemical Compounds in the Work Area who publish a list of recommended TLV's. Both organisations update these publications annually. Other countries usually employ one or the other of these sets of data as basis of their national documents, which also may be referred to.

4.2 Some common properties of gases and vapours

All gases and vapours will fully mix with all others by diffusion over time or if stirred. They will not separate out. However, some gases and vapours may react chemically with each other on mixing.

If a gas or vapour concentration is increasing in an area it is because more of that substance is arriving. It is not due to settling out.

Once gases and vapours have been mixed, they will stay mixed, unless a component is removed chemically, or is absorbed (for instance on a charcoal filter). Additionally, in the case of vapours, removal can be by condensation due to increased pressure and/or falling temperature.

The density of pure gases and the effective density of vapours is proportional to their molecular mass. There is no significant change of volume on mixing gases and vapours. Therefore the density of mixtures of gases and vapours may be simply calculated from the volume fractions and molecular masses of their components. If relative density data is available, the relative density can be similarly calculated from the volume fractions and relative densities of the components.

Air has an equivalent molecular mass of approximately 29, corresponding to a relative density of 1. For instance, gases with lower molecular masses than 29 will have a relative density less than 1 and will be lighter than air.

Mixtures of fresh air with pure or mixed gases that are lighter than air, will still be lighter than air, but less so. They will tend to rise until they become so diluted with fresh air that the effect becomes negligible.

Mixtures of fresh air with gases or vapours that are heavier than air, will still be heavier than air, but less so. They will tend to flow into low spots; pits, trenches etc, until they become so diluted with fresh air that the effect becomes negligible.

If a source of release and its surrounding air is substantially hotter than the ambient air the released mixture can rise initially, even if the relative density is greater than 1. As a rule of thumb, a temperature rise of 30 K will overcome what by calculation would be 10 % greater relative density than air. The converse applies where the release is colder than the ambient temperature.

Because of temperature differences at release and normal turbulence, gases and mixtures with relative density between 0,8 and 1,2 generally can be considered as having a similar relative density to air, and therefore are capable of propagating in all directions.

All flammable gases and vapours will have an LFL and a UFL. The LFL and UFL are experimentally determined, and this data for many substances can be found in IEC 60079-20. These values cannot be predicted with any accuracy.

NOTE Because this is experimental, different countries specify different values for LFL and UFL values, which have a legal standing. As two examples:

- NFPA 30 is a publication used within the USA.
- GESTIS is a publicly available database used within Germany.

All vapours, except water vapour, are toxic to varying extents. All flammable vapours are toxic at levels well below 25 % of LFL, most are toxic below 1 % of LFL. At best, gases (except air or oxygen) are asphyxiants (i.e. their effect on personnel is only due to them diluting the oxygen content of the air). Other gases vary from mild to extreme toxicity.

When detecting specific gases or vapours, it is necessary to be aware of the potential toxicity of other gases or vapours that might be present, but are not being detected.

4.3 The differences between detecting gases and vapours

The major practical differences between the detection of gases and the detection of vapours are outlined below.

4.3.1 Detection of gases

Substances that remain gaseous under the range of temperatures and pressures relevant to the gas detection application will closely follow the Gas Laws and behave predictably. Basically, simple training will suffice for a normal person.

Gases may be pure, or any mixture of gases can be made, unless they react chemically. The composition of non-reacting gas mixtures does not change with temperature or pressure.

4.3.1.1 Calibration considerations

It is possible to make and store under high pressure, calibration and other test gas mixtures fully representative of the intended gas detection application. Many can be made with a dry or synthetic air background. However the more-reactive gases tend to have longer storage life if the background is specially dried nitrogen, and this is normally chosen unless it is incompatible with the sensor.

Where more than one flammable gas (or vapour) may need to be detected, it is most common to use a single calibration or test gas, and relative response data. For further details see 4.3.2.1.

4.3.1.2 Propagation and sampling considerations

Gases can have a density that is lighter than air, such as hydrogen and methane. They can have approximately the same density as air, such as carbon monoxide, hydrogen sulphide, hydrogen cyanide, ethane, ethylene and acetylene; or they can have a density heavier than air such as chlorine, carbon dioxide, sulphur dioxide, LPG, propane, propylene and butane.

When sampling, at least some tests or readings should be taken in locations with the density of the gas in mind. This may also help to detect the source of release.

4.3.1.3 Toxicity considerations

Some flammable gases (specifically ammonia, hydrogen sulphide, hydrogen cyanide, carbon monoxide, methylamine and formaldehyde) are highly toxic at levels which are so low as to be undetectable by conventional flammable gas apparatus, although they are listed in IEC 60079-20 and can be detected by such apparatus at the much higher levels relevant to detection in LFL ranges. If these gases are likely to be present they will require separate and specific toxic gas sensors, and possibly other precautions, if personnel can be in the area.

Also it is necessary to be aware that some non-flammable gases are highly toxic, such as chlorine, sulphur dioxide, nitric oxide and nitrogen dioxide. If these gases are likely to be present they will require separate toxic gas sensors, and possibly other precautions.

Other flammable gases such as propane, cyclopropane, butane and LPG are mildly toxic or narcotic at levels well below their LFL. Similarly non-flammable gases such as carbon dioxide and nitrous oxide are potentially toxic at levels that may not result in a significant oxygen deficiency.

4.3.1.4 Water vapour

Although this subclause relates only to detecting gases, it is not normally possible to ignore water vapour. This can produce problems in cold apparatus that have been suddenly exposed to a hotter and humid atmosphere. Examples of this situation are in leaving a cold store and entering a normal atmosphere, or in leaving an air-conditioned situation and entering into a humid tropical or sub-tropical atmosphere. Water can condense in or on a sensor, causing a temporary loss of sensitivity or some other problem, until the apparatus warms up and the water re-evaporates. This is particularly the case with electrochemical sensors: A very rapid drop in an oxygen reading can occur from a normal 20,8 % or 20,9 % reading to 16 % or lower, due only to a coating of water condensing onto the cold sensor membrane. The sensitivity may then only recover slowly over some minutes as the sensor warms up to ambient, and the film evaporates.

Water vapour may also cause significant deviations of the reading of several types of sensors (see Clause 5 and Annex A).

4.3.2 Detection of vapours

Vapours are more difficult to understand than gases. Substances, where the liquid or solid can coexist with their gaseous state at normal or slightly abnormal temperatures and pressures are said to have vapours. Vapours behave differently to gases, and can present more problems. Where vapours are likely to be found, additional training in their properties is required.

Where a liquid is present, the rate of evaporation will increase with temperature. Similarly the maximum volume fraction of the vapour that can be achieved in a closed system (saturated vapour) will increase with temperature. This is dependent on the temperature and pressure and is independent of the quantity of liquid, provided there is some liquid remaining. The maximum volume fraction of the vapour is also independent of the background gas provided it is at the same temperature and pressure, and is not soluble in the liquid.

The volume fraction that can be reached by the vapour at any temperature is inversely proportional to the absolute pressure. So an increase in pressure can cause condensation.

As a rule of thumb, at constant pressure, the maximum (saturated) volume fraction of any vapour will increase by a factor between 1,5 and 2,0 for each 10 K rise in liquid temperature, and will fall by a factor of 1,5 to 2,0 for every 10 K reduction.

The effect of doubling the absolute pressure has an equivalent effect to a decrease in temperature of 10 to 17 K at constant pressure. Halving the pressure has an effect equivalent to a similar rise in temperature.

The temperature at which the saturated volume fraction can reach 100 % at the prevailing pressure is the boiling point.

It is only possible to have 100 % volume fraction of a vapour at or above the boiling point at that atmospheric pressure. Below the boiling point of the liquid, the maximum possible concentration of vapour in air or other gases must be less than 100 % volume fraction.

The actual amount of vapour will be less than the amounts predicted above if fresh atmosphere is being continually passed over the liquid surface, or if there has not been enough time for equilibration to be established. However this maximum amount can be achieved in an enclosed space, particularly if it has been closed for some time and the air space is slowly stirred by convection or mechanical means.

Flammable liquids have flashpoints, which are determined in a different way from LFL, but are essentially the temperatures at which their vapours can reach their LFL volume fractions in the air above their liquid surfaces, again provided that the vapour is not continuously removed by air currents.

All of these points impose limits on mixtures of vapours with gases. For any particular volume fraction of a vapour in a mixture with gas, a fall in temperature or increase in pressure will, at a certain stage, reach the saturation point, below which liquid will start to condense as a fog or liquid. When applied to water vapour this is known as the "dew point". This term is frequently applied to other vapours. Below the dew point the composition of any vapour-gas mixture must therefore change.

4.3.2.1 Calibration considerations

Real restrictions on what calibration or test vapours are practical for field use are imposed by the minimum temperature at which they will be used, and the required pressure in a calibration gas or test gas cylinder.

Test kits with a stored pressure in the range 2 MPa to 3 MPa are effectively limited to around 50 % LFL for n-pentane (boiling point 36 °C), about 10 % LFL for n-hexane (boiling point 68 °C), rather less for other substances with similar boiling points, and lower values still for substances with higher boiling points.

Generally, pentane and hexane test gases are directly applicable to the petroleum industry where such vapours can be the main components. However, for other industries, it is seldom possible to make a portable or transportable calibration or test kit for use outside a laboratory, that is truly representative of the vapour to be measured.

To get around this problem, responses of the apparatus to different gases and vapours with reference to a particular practical test gas or vapour are determined in a laboratory. Such data is time-consuming and expensive to obtain, and for general purposes is normally only done for a particular model of apparatus, not for each unit. In such cases there will be variations between different units.

Routine calibration is then effected in one of two ways:

- a) to give a correct LFL readout on the calibration gas or vapour and use the relative response data directly for the substance(s) of interest (or generate the relative response in software);
- b) to give an artificial LFL readout on the calibration gas or vapour so that the LFL readout will be approximately correct when exposed to the gas or vapour of interest, or to a specified range of gases or vapours

There can also be variations in relative responses of sensors over time, particularly in the case of sensors which have a definite life, or are susceptible to "poisoning" (loss of sensitivity due to chemical action), such as electrochemical and catalytic combustion sensors.

For instance, in the case of catalytic combustion sensors, the response to methane will selectively deteriorate before other gases or vapours. If this happens and the apparatus can be successfully re-calibrated on methane, it will over-read on all other substances, which is in the safe direction.

For this reason, in all catalytic combustion applications where methane could be involved, the use of methane response test gas is recommended for field tests and during calibration procedures, even if some other gas or vapour is used for the actual calibration. Otherwise propane, pentane, or hexane calibration mixtures are usually recommended for the reason that sensitivity to these will tend to fall before most other substances.

It should also be noted that the sensitivity of catalytic combustion sensors to methane in LFL terms is generally higher than the sensitivity to other substances except hydrogen. Consequently, if using the technique described in a) above, the alarms should be set to a lower set point, and if using the technique described in b) the calibration reading should be set to a correspondingly higher reading than the %LFL of the methane test gas.

Hydrogen should only be used as its own calibration gas.

Whenever test or calibration gases other than the gas or vapour of interest are used, it is recommended that additional safety margins, lower alarm settings etc. are employed in order to compensate for the added uncertainty of relative response data due to the factors mentioned above.

4.3.2.2 Propagation and sampling considerations

Only the vapour of water is lighter than air. There are only four vapours, three of which are flammable, with a similar density to air (methanol, hydroxylamine, hydrazine and hydrogen peroxide, the last three being uncommon).

All other vapours are more dense than air. Most are considerably more dense than air. At a point of release, unless heated, they will initially flow downwards or across level surfaces, and until they are well mixed with air they will stay close to the ground, possibly only a few centimetres deep, which is where they will present the greatest flammability problems. A severe instance of this is in the case of pits, trenches and tunnels which will tend to fill from the bottom upwards and can permit extensive propagation over hundreds of metres. This can also cause the most serious toxicity problems for personnel entering pits and tunnels.

When sampling for flammable vapours in relatively undisturbed atmospheres, some tests must be performed at very low levels, ideally within a centimetre of the floor or ground.

Once mixed with an excess of air, all vapours will be found at all levels, possibly at volume fractions well below their LFL but still presenting major toxicity problems

The vapour of a high flashpoint flammable liquid may not be detectable if the ambient temperature is well below the flashpoint. As an example, using the rule of thumb at the beginning of 4.3.2, if the ambient is 60 K below the flashpoint, it can be estimated that the vapour can only reach between 1 % and 8 % of LFL as a maximum, and then only slowly, close to the liquid, and if the vapour is not being blown away.

Conversely, if the temperature rises, and particularly in an enclosed area, the concentration can change dramatically. Again, using the rule of thumb, the vapour concentration in an enclosed space could increase by a factor up to eight for a 30 K rise in temperature, caused, for instance, by the sun on an external tank. A previously undetected amount of vapour while the tank was cold, could become very significant when it heated up. When temperatures are rising, frequent vapour testing is necessary.

Other problems can arise with substances of high molecular mass. The higher the molecular mass is, the lower the rate of diffusion will be. This applies to non-pumped apparatus where diffusion screens are used to prevent external ignition, and also within certain sensors. In particular this can adversely affect both the speed of response and the sensitivity in catalytic combustion sensors, particularly the "poison-resistant" varieties.

Major problems also arise in vapour testing due to the possible condensation of the sample itself in the detector or its accessories: Gas detectors will only detect the gases or vapours present. They will not detect mists or condensed liquids caused as a result of the apparatus, or a sample line, being markedly colder than the atmosphere being sampled.

If the apparatus or its sampling line gets contaminated by condensed vapour because it was too cold, or worse still if it gets contaminated by drawing up the flammable liquid, spurious, and possibly dangerously misleading, readings will occur until such contamination is totally removed.

4.3.2.3 Toxicity and other considerations

All vapours except water, and also including all non-flammable ones, are toxic to some degree. All flammable vapours are toxic at concentrations well below LFL. Most vapours, including many commonly found in industry, are of toxic concern well below 1 % of LFL. So they may be undetectable at concentrations where they are already a toxic problem if only using a combustible gas detector with a normal LFL range. Additional precautions are needed.

4.4 Oxygen deficiency

Oxygen deficiency detectors are frequently incorporated with flammable gas apparatus, with or without toxic sensors as well. Such oxygen detectors are essential for work in confined spaces.

Some varieties of oxygen sensors respond to changes in pressure, and so need checking in fresh air, and possibly adjusting, each time they are used and / or if there is a significant change of altitude.

The volume fraction of oxygen in dry air is about 20,9 % v/v. A typical oxygen deficiency alarm setting is between 19,0 % to 19,5 % v/v.

Taking as an example a setting of 19,0 % v/v, the alarm should operate on a 1,9 % v/v deficiency or, put another way, a deficiency of 10 % of the original concentration. In certain circumstances this may not be adequate for personnel protection.

Similarly, with a setting of 19,5 % v/v, the alarm should operate on a 1,4 % v/v deficiency or, put another way, a deficiency of 7 % of the original concentration. In certain circumstances this also may not be adequate for personnel protection on its own.

It is not commonly appreciated that if an operator is relying on apparatus to detect a flammable gas or vapour and a deficiency of oxygen, it is also necessary to know what could be the cause of any oxygen deficiency found.

There are three basic physical and chemical mechanisms by which oxygen deficiency can occur, described in the next three subclauses with reference to the 19,5 % v/v alarm setting example above.

4.4.1 Chemical reaction of oxygen, with solid products

The main examples are the rusting of steel or the corrosion of other metals. Oxygen has simply been subtracted from the air, and a solid oxide is left. This can typically happen in confined spaces constructed of metal.

When the alarm operates at 19,5 % v/v, the atmosphere is equivalent, in physiological terms, to working at an altitude about 650 m higher than the current altitude. Normally this will not cause any health problem to personnel.

4.4.2 Chemical reaction of oxygen, with gaseous products

In the simplest case this could be the result of respiration, aerobic bacterial action (but not anaerobic action), or clean combustion. The 1,4 % reduction in oxygen content needed to set off the alarm would be accompanied by an increase in carbon dioxide level of about 0,8 %, which is fairly safe in the short term, and there would be no short-term or long-term effects on a 'normal person'.

If, however, the oxygen deficiency was the possible result of 'dirty' combustion involving wood, paper, coal, oil, etc, then, even after the smoke had settled, an atmosphere with 19,5 % v/v oxygen remaining could be lethally toxic due to amounts, possibly in excess of 0,2 % v/v (2 000 parts per million), of carbon monoxide produced together with the carbon dioxide.

If the combustion had also involved plastics such as PVC, polyurethane etc, the atmosphere would be very toxic due to additional combustion products such as hydrogen chloride and hydrogen cyanide.

4.4.3 Dilution of the air by displacement by some other gas or vapour

NOTE Detection of a gas by oxygen depletion is only recommended under very controlled conditions and is not otherwise recommended.

The 1,4 % v/v oxygen deficiency needed to cause the alarm would require an addition of 7 % v/v of the other gas or vapour. So the problem becomes that of knowing what gas or vapour has caused the deficiency. There are several categories:

- a) If the cause of the oxygen deficiency is dilution by one of the inert gases such as nitrogen, argon, helium or neon, (or water vapour) an addition of 7 % v/v of the inert gas to the atmosphere is perfectly safe. The situation is similar to that in 4.4.1.
- b) If the gas causing the oxygen deficiency is hydrogen, methane (natural gas) or ethane, the atmosphere would be safe to breathe for a short period but would be above the LFL, and therefore explosive. But if there was a flammable gas detector as well as the oxygen detector, it should have given an alarm well before this dangerous situation occurred.
- c) If the gas causing the oxygen deficiency is acetylene, ethylene, cyclopropane, propane, LPG or butane, the atmosphere would possibly be survivable by persons working in the area for a few seconds at least. But it would be above the LFL. So if there was a combustible sensor as well, this would alarm first.
- d) If the gas causing the oxygen deficiency is carbon dioxide, the atmosphere would be marginal. Persons could only stay conscious in such an atmosphere for a short while. A 7 % volume fraction of any other gas or vapour added to the atmosphere, causing that amount of oxygen deficiency, would render the atmosphere potentially and rapidly fatal.

WARNING – Oxygen detectors must never be used to indicate displacement by CO₂.

This may lead to a very dangerous situation. Reliance on oxygen alarms to monitor the production of carbon dioxide has led to fatalities. These were due to confusion between the situation in 4.4.2, where oxygen is subtracted and the alarm operates with around 0,8 % v/v CO₂, and the production of CO₂ by anaerobic processes. The latter situation is covered in this subclause, where CO₂ has been added without subtraction of oxygen, for instance in beer or wine making or by anaerobic slime in manholes. In these cases, the same alarm will not operate until there is 7 % v/v CO₂.

WARNING – An additional danger in this case is that some oxygen sensors give a small upscale signal with high concentrations of CO₂.

In the example above, this means that the O₂ reading will be higher than the actual concentration of O₂, and the 19,5 % v/v O₂ alarm would only be given at a significantly higher (and therefore more dangerous) concentration of CO₂ than 7 % v/v.

5 Measuring principles

The measuring principles are handled in full detail in Annex A. This clause is an extract of Annex A to provide practical information for aspects of operation, servicing and repair. Headlines and numbering of subclauses from 5.1 to 5.9.4 are identical with A.1 to A.9.4 of the annex. For more detailed information please use Annex A instead of this clause.

The measuring principles of various types of sensors are given below together with their advantages and typical applications and their limitations, interferences by other gases and poisoning (i.e. loss of sensitivity caused by other gases or vapours).

A summary of the most common detection principles is given in Table 1 below. These are explained in more detail in 5.1 to 5.9 (and in A.1 to A.9).

Table 1 – Overview of gas detection apparatus with different measuring principles

	Catalytic sensor	Thermal conductivity sensor	Infrared sensor	Semi-conductor sensor	Electro-chemical sensor	Flame ionisation detector	Flame temperature analyser	Photo ionisation detector	Para-magnetic oxygen detector
Details in subclause	5.1	5.2	5.3	5.4	5.5	5.6	5.7	5.8	5.9
O ₂ required in gas sample	Yes	No	No	(No)	(No)	(No)	Yes	No	Not applicable
Typical measuring ranges Combustible gases	≤ LFL	(0)–100 %	0–(100) %	≤ LFL	≤ LFL	≤ LFL	< LFL	< LFL	Not applicable
Typical measuring ranges for oxygen	Not applicable	Not applicable	0–(100) %	Not applicable	0-25 % (0-100 %)	Not applicable	Not applicable	Not applicable	0-100 %
Combustible gases not measurable	Large molecules	See 5.2	H ₂	(See 5.4)	Alkanes	H ₂ ; CO	(see 5.7)	H ₂ ; CO; CH ₄ IP>X ⁵	Combustible gases
Relative response time ¹	Depends on substance	Medium	(Low)	Depends on substance	Medium	Low	Low	Low	Low to medium
Interference of non-combustible gases ²	No	CO ₂ ; Freons	(Yes)	SO ₂ ; NO _x H ₂ O	SO ₂ ; NO _x	ClHCs ³ ; Halon	(Halon)	Substance IP < X ⁵	NO; NO ₂
Poisoning ²	Si; (Hal ⁴); (H ₂ S); Pb	No	No	Si; Hal ⁴ ; SO ₂	(No)	(Si)	No	No	No
External gases required	No	No	No	No	No	Yes	Yes	No	(Yes/No)

NOTE 1 Qualitative comparison between principles. The values do not take into account time for aspirated sampling lines.

NOTE 2 Table gives common examples.

NOTE 3 Chlorinated hydrocarbons.

NOTE 4 Organic halogenated or inorganic halogen compounds.

NOTE 5 IP is the ionisation potential of the substance; X is the detector UV-lamp energy.

(No),(Yes) For information on the statements in brackets, refer to the corresponding subclause.

5.1 Catalytic sensors

The principle of operation of catalytic sensors depends upon the oxidation of flammable gas on the surface of an electrically heated catalyst typically operating at a temperature between 450 °C and 550 °C.

Catalytic sensors are capable of continuous operation for a few years in the absence of major poisoning, but will progressively drift and lose sensitivity due to ageing and traces of poisons. For this reason regular response checks and recalibration is required, the frequency depending on the severity of the application.

Sensor enclosures in most cases incorporate a permeable metal device to allow gas to reach the sensing element and to ensure that if the gas is above LFL and is therefore ignited by the hot sensing elements, this does not ignite the atmosphere outside the enclosure. This protection is also useful against dust or mechanical damage, as well as protection against excessive air velocities.

5.1.1 Common applications

Catalytic sensors are suitable for:

- the detection in principle of all flammable gases, but with variations in sensitivity;
- the detection of gas/air mixtures up to the lower flammable limit (LFL).

The response time and sensitivity depend on the individual gas to be measured. The larger the molecular mass and molecular size of the gas, the longer will be the response time, and generally, the lower will be the sensitivity.

5.1.2 Limitations

The catalytic sensor depends upon catalytic oxidation for its principle of operation and it functions only when sufficient oxygen (min. 10 %) is present. Insufficient oxygen concentration may occur at high flammable gas concentrations well above the LFL. Therefore, this type of sensor can only be used for the detection of gas/air mixtures up to the lower flammable limit.

WARNING – With concentrations above the lower flammable limit, a catalytic sensor may erroneously indicate that the concentration of flammable gas is below the LFL.

Therefore, apparatus fully complying with IEC 60079-29-1, or the former IEC 61779 series, using catalytic sensors must have a locking overrange indication to prevent erroneous readouts due to this. However, stand-alone sensors (e.g. 4-20 mA transmitters) and older apparatus may not provide such protective features.

Changes of pressure, temperature and humidity have no significant effect within the specified range. However the lower the alarm level is set the greater will be the significance of variations in temperature and other environmental factors.

To prevent false alarms, it is recommended that the alarm level should not be set below 5 % LFL for methane, 10 % LFL for propane and butane and 20 % LFL for gasoline vapours, provided suitable precautions are taken against toxicity in the last case.

After exposure to concentrations of gas in excess of the measuring range, or for prolonged periods, the sensor may need a recovery time of several hours or may have irreversible changes to its zero gas reading and sensitivity.

For reasons given in the last three paragraphs, the sensors are not suitable for high sensitivity applications (e.g. ranges much less than 0 – 10 % of LFL), as amplification would merely amplify these undesirable features

5.1.3 Interferences

The measuring principle is generally not selective because all flammable gases (in air) induce a signal. There is a wide variation in sensitivity to different gases which is not directly correlated to the LFL. However, it is possible to use the verified relative sensitivity (as supplied by the manufacturer) for the gas to calibrate the apparatus.

If the atmosphere to be monitored contains gas or gases that dilute or displace air, for example nitrogen or carbon dioxide, the catalytic sensor may give a low or even zero response. Similar problems may occur in steam-laden atmospheres, quite often owing to saturation of the sintered flame arrestor due to condensation. High concentrations of inert gas (for example argon or helium) may also change the thermal balance of the sensor resulting in apparent reading of combustible gas.

5.1.4 Poisoning

Catalytic sensors are susceptible to poisoning by substances many of which are not obviously present but are fairly widely used, necessitating regular response checking and recalibration.

This inhibition may be permanent or temporary according to the nature of the contaminant.

Permanent inhibition, usually known as "catalyst poisoning", may result from exposure to such substances as

- silicones (e.g. waterproofing, adhesives, release agents, special oils and greases, certain medical products);
- tetraethyl lead (e.g. leaded petrol, particularly aviation petrol 'Avgas');
- sulphur compounds (e.g. sulphur dioxide, hydrogen sulphide);
- halogenated compounds (e.g. some halogenated hydrocarbons);
- organo-phosphorus compounds (e.g. herbicides, insecticides, and phosphate esters in fireproof hydraulic fluids).

In some cases, halogenated hydrocarbons and sulphur compounds may only cause temporary inhibition.

So-called "poison resistant" sensors can tolerate higher doses of these contaminants than traditional sensors before they suffer inhibition. In achieving this their other properties may suffer (e.g. they may have a lower speed of response and reduced sensitivity).

Those that are not “poison resistant”, in some cases, may be protected against most poisons by the use of activated carbon or other types of filter. However, filters should be used with great care because, while they may offer excellent protection from contaminants, carbon filters in particular will cause a reduced sensitivity to, and may even prevent the detection of, higher hydrocarbons. They also may result in considerably extended response times for substances other than methane or hydrogen, effectively limiting their application to these gases. Filters have a limited lifetime and require replacement. Their performance may also be affected by the level of humidity in the atmosphere.

The effect of poisoning depends on the poison itself, the gas to be measured and the particular design of the sensor. The manufacturer's guidance should be sought regarding which contaminants may poison the catalyst and how the sensor may be protected.

5.2 Thermal conductivity sensors

The principle of operation of the thermal conductivity sensor depends upon the heat loss by conduction (and sometimes convection as well) of an electrically heated resistance element (i.e., filament, bead or thin film resistor) located in a gas sample stream of constant flowrate, or in a diffusion chamber.

The sample is not consumed or altered by the sensor, and it does not require oxygen. Therefore, the reading may even be taken with a stopped flow.

This type of sensor is suitable for monitoring those gases whose thermal conductivity in the desired detection range differs greatly from that of the reference environment (usually air). However, published tables of thermal conductivity may be misleading as other effects like convection or mass transport also influence the sensitivity of the sensor.

5.2.1 Common applications

These sensors do not require oxygen for their operation and are capable of measuring concentrations up to 100 % v/v gas.

The apparatus may be calibrated in any suitable range up to 100 % of a nominated gas in a nominated background gas.

These sensors are suitable for detecting individual gases of high or low conductivity, relative to air, where air is the reference environment. Typically the high conductivity gases hydrogen, helium and neon have a good sensitivity in air, and the sensitivity for methane is usually acceptable.

The sensitivity is often limited and the minimum practical detection limit may exceed the LFL unless the thermal conductivity of the gas is sufficiently different from that of air.

A special application is for the purging of LPG tanks with CO₂/N₂ ‘inerting’ gas. When thermal conductivity is combined with convection it is possible to produce sensors which are largely independent of a range of background gases (e.g. air, nitrogen and certain carbon dioxide / nitrogen ‘inerting’ gases). At the same time these will respond with at least comparable sensitivities to a range of lower hydrocarbons from methane to pentane, although thermal conductivity data alone would indicate that this is not possible.

5.2.2 Limitations

The technique is limited to applications where anticipated variations to the background gas have a negligible effect when compared to the response(s) of the gas or gases of interest in the required range.

The sensors are not selective for individual gases. They will respond to all gases whether flammable or not.

The thermal conductivities of flammable gases differ widely. Lighter gases (e.g. methane and hydrogen) are more conductive than air whereas heavier gases (e.g. non-methane hydrocarbons) are less conductive. The response to a gas mixture is therefore indeterminate unless the proportions of all the constituent gases in the mixture are known. In the worst case, a mixture of high and low conductivity gases could cancel each other out and produce no apparatus response.

Errors may also result if

- a) a flow-sensitive type of thermal conductivity sensor is used and the gas sample flow is not stable, or if the recommended conditions of gas flow are not maintained as per the manufacturer's instructions;
- b) there are variations in ambient temperature without compensatory ambient temperature control on the complete sensor;
- c) the apparatus is used in an unintended orientation, particularly if it is a type employing convection as well as conductivity

5.2.3 Interferences

Interference or errors will be caused if the apparatus is exposed to, or is used to attempt to detect, gases for which it is not calibrated. Specifically additional or unanticipated gases whether flammable or not, of different thermal conductivities to the background can affect the resulting conductivity in either direction, so that the signal may even be reduced to zero.

A specific interference in many cases is water vapour since it can be highly variable, particularly in hot climates. In the higher sensitivity applications the signal due to likely water vapour variations may be sufficient for the apparatus to require sample conditioning.

5.2.4 Poisoning

There are no known poisoning effects.

5.3 Infrared sensors

The principle of operation of spectrophotometric optical sensors depend upon the absorption of energy of a beam of light, in the ultra violet, visible, or infrared parts of the spectrum, by the molecules of the gas being detected. Most existing apparatus operates within the infrared (IR) spectrum.

Infrared sensors do not consume the sample, and they do not require oxygen for their operation. They are largely unaffected by flow rate. Sensor life is expected to be long in the absence of corrosion, contamination or mechanical damage.

The principle of this type of apparatus allows the use of self-diagnostics to verify the response to the gas. Other advantages include

- a) high stability capability;
- b) no ambiguity at concentrations above the LFL;
- c) immunity to poisoning effects;

- d) reduced maintenance through self diagnostics. Automatic calibration, checking capabilities for malfunctions of the infrared source, and compensation for dirt accumulation on the optics, may extend operation periods between service. However, special consideration should be given to clogging of protective filters in the gas path since this will not normally be detected by self diagnostics.

5.3.1 Common applications

Infrared sensors are calibrated to detect a particular gas or, in some cases, a range of gases. Other gases will not be detected if their infrared absorption band is outside that of the calibration bandwidth. Apparatus incorporating such sensors should therefore be used only for the detection of gas mixtures for which they have been calibrated.

Infrared detectors can not respond to hydrogen. However, they may be used for the detection of most other flammable gases, in any specified range of concentration from a few hundred parts per million up to 100 % v/v gas. The longer the optical path is made, the higher will be the sensitivity. Measuring range and performance should be selected according to each application.

5.3.2 Limitations

These sensors will not detect hydrogen.

Pressure variations do not affect the zero gas reading, but sensitivity is normally proportional to partial pressure. Since the sensor is sensitive to pressure, care should be taken to prevent alteration to the gas outlet pressure of the apparatus, see instruction manual.

Some types of sensor relying on intermittent infrared beams or photoacoustic principles are susceptible to vibration.

Some types of infrared sensors, particularly open-path designs, are sensitive to misalignment caused by shock and vibration.

Temperature effects are usually small but may increase or decrease the signal.

5.3.3 Interferences

Other components (combustible or non combustible) may induce a signal. Serious errors are likely to occur with some detectors due to interfering gases such as carbon dioxide.

Variations of water vapour concentration in the background gas can cause interference with many applications, including general-purpose infrared flammable gas detectors. However, apparatus for this purpose that complies with the requirements of IEC 60079-29-1 will have minimal interference with water.

Solid and liquid contaminants will also absorb infrared energy, causing interference or loss of sensitivity. It is important to prevent contamination of the optical components (e.g. windows and mirrors) by particulate matter or condensation. When particulate filters are used to keep optical components clean, they may become blocked under excessively dirty conditions.

5.3.4 Poisoning

There are no known poisoning effects.

5.4 Semiconductor sensors

The principle of operation of the semi-conductor sensor depends upon changes of electrical conductance that occur by chemisorption on the surface of the heated sensing element when exposed to gas other than air. Gas concentrations are inferred by measuring the change of resistance.

The semiconducting material is electrically heated up to a few hundred degrees Celsius. Electrodes are implanted or otherwise mounted on the surface.

Response times depend on the manufacturing properties of the sensing element, the concentration of the gas to be measured, and the gas transport system to the sensor (mostly by diffusion but aspiration may be used).

5.4.1 Common applications

Semiconductor sensors may be used for the detection of gases over a wide range of concentrations, including very low concentrations, however, they have a non-linear response.

They are suitable for leak detection, even at very low concentrations, and for alarm-only apparatus.

5.4.2 Limitations

Semiconductor sensors for flammable gases are generally non-specific, vulnerable to both humidity changes and interfering gases and may exhibit drift both of zero and span. Some gases, for example NO₂, produce negative signals.

NOTE Normally, the manufacturer will give guidance on substances that will inhibit operation of the sensor or produce false indications.

New sensors may need a long "burn in time" (up to weeks) for stabilisation of zero and sensitivity before calibration. This preconditioning should be carried out by the manufacturer. Further preconditioning may be necessary after long periods (> 1 day) without power.

After exposure to concentrations of gas in excess of the measuring range, the sensor may need a recovery time of several hours or may have irreversible changes to its zero gas reading and sensitivity.

5.4.3 Interferences

The measuring principle is not selective, non combustible gases may induce a negative or a positive signal.

There is a wide variation in sensitivity between sensors of the same type to particular gases and in addition, the relative sensitivity for these gases may vary significantly from one sensor to another. In general, there is a very wide variation in sensitivity to different gases which is not directly correlated to the LFL. Refer to the instruction manual.

Variations of oxygen concentration, temperature, humidity or air speed may have a strong influence on the sensitivity. Refer to the instruction manual.

5.4.4 Poisoning

The sensitivity may be strongly affected (mostly decreased, but in some cases increased) by poison concentrations higher than those which affect catalytic sensors. Examples of such poisons are:

- basic or acidic compounds;
- silicones;
- tetraethyl lead;
- sulphur compounds;
- cyanides;
- halogenated compounds.

The manufacturer's guidance should be sought regarding which poisons affect the sensitivity of the sensor and how the sensor may be protected.

5.5 Electrochemical sensors

The principle of operation of electrochemical sensors depends upon the change of the electrical parameters of electrodes in contact with an electrolyte when a specific gas is present. The change in the electrical parameters occurs due to a chemical reduction / oxidation (redox) reaction of the gas of interest at the surface of an electrode.

The sensors require recalibration at suitable intervals to correct for drifts in zero and sensitivity, and ultimately require replacement. Typical lifetimes under favourable conditions can exceed 2 years.

5.5.1 Common applications

Electrochemical cells are not available for detecting most hydrocarbons (for example the alkanes, methane, ethane, propane, etc.). However, there are a limited number of applications of this type of sensor for explosion prevention. They are suitable for measuring concentrations of hydrogen or carbon monoxide up to the LFL, and oxygen up to 25 % v/v. There are also sensors available for up to 100 % (v/v oxygen).

Additionally, these sensors are commonly used for measuring concentrations of toxic gases down to low parts per million levels. Portable apparatus for the detection of flammable gases, using other types of sensor described in this standard for their 0 % - 100 % LFL ranges, frequently have such electrochemical toxic gas sensors and electrochemical oxygen sensors fitted in a multi-gas configuration.

5.5.2 Limitations

Temporary, loss of sensitivity occurs in moving a cold sensor of this type into a warmer high humidity situation due to water condensing on the membrane, partially blocking it. This is particularly noticeable on oxygen sensors where a normal reading of just under 21 % can drop for this reason and give an alarm for a few minutes. Contamination by non-volatile liquids or adhesive solids can have a similar but permanent effect.

Dependent on the sensor, oxygen may be required for the electrochemical reaction. In such cases dissolved oxygen in the electrolyte will last for short periods, but prolonged operation in oxygen-free situations is not possible.

The electrolyte or one or more of the electrodes will usually limit the life of the sensor. The sensitivity will usually fall with time, requiring periodic recalibration or response checking.

Dependent on the type of sensor and the gas to be measured, the sensor may have a shortened life or a drop in response due to an overload of gas. This can happen particularly with oxygen sensors used in high oxygen concentrations, where a lead electrode is consumed proportionally to the oxygen exposure.

The lifetime of many types of sensor is also dependent on the dose of other gases because the electrolyte will be consumed. In particular, high concentrations of carbon dioxide can result in loss of sensitivity and shorten the electrolyte life in certain oxygen sensors.

Low temperature or humidity may reduce the sensitivity and increase the response time of the sensor. Prolonged operation in very low humidities can dry out the electrolyte. However, some sensors have a reservoir containing material for maintaining humidity in order to avoid this effect. Electrolyte properties will limit the low (and in some cases the high) temperature operation, see the instruction manual. There is usually a restriction around $-15\text{ }^{\circ}\text{C}$ due to potential freezing.

Response time and recovery time $t(90)$ are comparatively long, typically $\geq 30\text{ s}$.

5.5.3 Interferences

Electrochemical cells may respond to other gases with a positive or negative change in signal.

With the exception of oxygen sensors, the sensitivity to interference may be in some cases higher than to the gas to be measured, refer to the instruction manual.

For some types of electrochemical sensors the sensitivity is proportional to atmospheric pressure. Other types of sensor are affected or damaged by pressure pulses, refer to the instruction manual.

There are specific interference effects for oxygen sensors arising from their use in non-air gas mixtures or in the presence of very high concentrations of combustible gases, such as:

- the molecular mass of the gas in which the oxygen is measured may have a strong influence on the sensitivity of the sensor. Therefore, calibration should be carried out using a defined concentration of oxygen in the same gas;
- the lifetime of the sensor may be reduced by high concentrations of organic solvents which react with the electrolyte.

5.5.4 Poisoning

The electrolyte or the electrode may be affected by other gases resulting in a loss of sensitivity, see the instruction manual.

Apart from contamination as discussed above, the gas inlet of the sensor or membrane may be gradually reduced or even blocked by reaction products, for example, from hydrolysis of halogenated compounds like boron trifluoride (BF_3), silicone tetrachloride (SiCl_4) etc.

Some oxygen sensors may lose their sensitivity due to high concentrations of CO₂ in the atmosphere reacting with their electrolyte.

5.6 Flame ionization detectors (FID)

The operating principle of the flame ionization detector depends upon the ionization (electrical charging) of organic compounds as they are burnt in a detector with an internal hydrogen flame. The ion cloud so formed migrates under a potential gradient of up to a few hundred volts maintained between electrodes in the combustion chamber. This results in a very low electric current, proportional to the concentration of gas/vapour in the gas stream.

Inert and rare gases, nitrogen oxides, halogens, nitrogen, oxygen, carbon dioxide, carbon tetrachloride, and water give no response.

5.6.1 Common applications

This type of sensor is used where high sensitivity, wide measuring range, small measuring uncertainty, poison resistance and fast response time, below 1 s. can be obtained, are of main interest. The sensor is suitable for measuring ranges from the parts per million level up to the LFL and even above.

Almost all organic compounds, most of that are flammable, will give a signal; The notable exceptions are formaldehyde and formic acid which do not give a response.

This type of sensor is suitable for the measurement of gas at elevated temperatures.

5.6.2 Limitations

The principle of operation is not selective because generally all organic compounds cause a signal. If different gases are expected at the place of operation, the sensor should be calibrated for that gas to which the apparatus is least sensitive. Within limits, however, relative responses are more calculable than other techniques

Apart from the few organic exceptions already mentioned, these sensors are also not suitable for the flammable inorganic gases; hydrogen, carbon monoxide, ammonia, carbon disulphide, hydrogen sulphide and hydrogen cyanide.

The sensors will also detect some organic compounds which are not flammable

External gases, hydrogen and (usually) synthetic air for its combustion are required. The signal is critically dependent on both sample and hydrogen flow rates, and less so on the combustion air flow. Therefore pressure of the gas sample, air and flammable gas should be kept constant, but it should be noted that the flame arrestors used in the sampling line can be soiled and difficulty may be experienced in keeping the sample flow constant.

5.6.3 Interferences

Halogenated hydrocarbons reduce the response when the apparatus is calibrated for measuring the total carbon content of the gas mixture.

The sensor cannot be used with high concentrations of gases that will extinguish the flame for example halons.

5.6.4 Poisoning

Generally there is no poisoning effect, but if silicones or other substances that result in solid combustion products are present, they may result in a coating of the electrodes and insulation which will reduce the sensitivity and ultimately make the sensor inoperative.

5.7 Flame temperature analysers (FTA)

The operating principle of the flame temperature analyser detector depends upon the rise in temperature of a flame burning a constant flow of hydrogen (or some other gas) by flammable contaminants in the air sample supporting the flame's combustion.

5.7.1 Common applications

This type of sensor is used to measure the total amount of flammable gases and vapours below the LFL when a fast response time is required. Response times below 5 s can be obtained.

This sensor is suitable for the measurement of gas at elevated temperatures.

5.7.2 Limitations

It is non-specific as the response depends only on the calorific nature of the sample. At higher concentrations the response is not linear. For range limitations refer to the instruction manual.

The analyser is not recommended for measurement in parts per million ranges.

External gas(es) are required. Hydrogen or another fuel is required for the flame. Either oxygen is required in the gas to be measured, or a separate air supply needs to be provided for the burner. The signal is critically dependent on the flow rates of sample, fuel, and, where used, combustion air. Therefore, as in FID, pressure of the gas sample, air and flammable gas should be kept constant, but it should be noted that the flame arrestors used in the sampling line can be soiled and difficulty may be experienced in keeping the sample flow constant.

5.7.3 Interferences

Halogenated hydrocarbons, such as halons at high concentrations may decrease the signal by reduction of the flame temperature or even may extinguish the flame.

5.7.4 Poisoning

There is no known poisoning effect.

5.8 Photo ionisation detector (PID)

This detection principle is based on ionisation of gases by ultraviolet (uv) radiation from a special lamp of known wavelength, and hence photon energy, usually quoted in electron-volts eV (e.g. 10,6 eV).

The technique is not specific to flammable gases, and with the more common ultra violet lamps, it will not detect all flammable gases.

Ionisation potential of various substances can be found in the literature or a list may be obtained from the apparatus supplier.

5.8.1 Common applications

This type of sensor is used where high sensitivity, poison resistance and fast response time, typically between 2 s and 10 s, are the main requirements.

Although the technique is suitable for fixed operation, the apparatus may be portable (hand held) or transportable type and usually will have an aspiration pump built in. In this form the technique is suitable as spot reading apparatus.

This sensor is suitable for the measurement of gas concentrations from low parts per million range up to approximately $2\,000 \times 10^{-6}$. Thus it is suitable for measurements from toxic levels to low percentages of LFL.

Additionally, this type of sensor is commonly used for measuring gas concentrations down to low parts per million levels for short periods of time, for example, in leak detection.

5.8.2 Limitations

The measuring principle is not selective for combustible gases. It will detect all substances which have an ionisation potential (IP) lower than the energy of the UV-lamp and will not detect compounds having an IP higher than the lamp energy. Most sensors have a UV lamp with an energy of 10,6 eV. The higher energy lamps tend to have reduced lifetimes.

The sensor can not detect carbon monoxide, hydrogen, or methane in air.

Thus it is unsuitable for low alkanes and some other substances, however, lamp energies may range from 8,4 eV (which will eliminate many other substances) to 11,7 eV for use in air, which will permit more gases to be detected, (refer to the documentation of the apparatus).

This type of sensor is not recommended for measuring higher concentrations than about $2\,000 \times 10^{-6}$ because the response is not linear. For range limitations refer to the instruction manual.

5.8.3 Interferences

The response factor depends strongly on the ionization properties of the gas.

Humidity may induce a signal equivalent to several parts per million. This signal is not related to ionisation (IP of H₂O is 12,6 eV) but may be caused by an interaction with material surrounding the electrodes.

A high concentration of methane in the presence of the substance to be detected may reduce the reading by inhibiting the ionisation.

Condensed material, solid material, fingermarks, etc., on the lamp or cell windows can alter the ultraviolet intensity and hence the sensitivity.

5.8.4 Poisoning

Generally, there is no known poisoning effect.

The measurement of certain compounds like esters or styrene may lead to decomposition products being deposited on the UV lamp. Therefore regular cleaning of the UV lamp is recommended (refer to instruction manual).

5.9 Paramagnetic oxygen detector

Oxygen is strongly paramagnetic (attracted to a magnetic field). Gases containing oxygen will tend to be drawn into a strong magnetic field with a force proportional to the oxygen fraction. NO and NO₂ will be drawn to a proportionately lesser extent and other gases have a negligible effect, making the technique effectively highly specific for oxygen in the absence of appreciable amounts of nitric oxide.

5.9.1 Common applications

This type of sensor is used for measurement of oxygen where selectivity, long term stability, and poison resistance are the main requirements.

This sensor is suitable for the measurement of oxygen concentrations in ranges between 0 % to 1 % v/v and 0 % to 25 % v/v oxygen. Measurement of up to 100 % v/v is possible. The difference between the lower and upper limits of the measuring range has to be greater than 0,5 % v/v oxygen.

Dependent on the particular detection method used, response times between 6 s and 40 s are typical.

5.9.2 Limitations

Dependent on the particular detection method used, the apparatus may:

- contain ignition sources (heater);
- be sensitive to shock and/or vibration.

In most cases pressure and/or temperature correction is necessary.

5.9.3 Interference

Except for NO and NO₂, which give signals of around 50 % and 4 % respectively of the oxygen signal at equivalent concentrations, there are no significant interference by other gases.

5.9.4 Poisoning

There is no known poisoning effect.

6 Selection of apparatus

In this clause and Clauses 8 and 9, there is a need for documentation of plant information, site information and decisions to be made. The documentation can be quite extensive, particularly for large fixed systems, and should be in an easily audited dossier. It is important that this is kept updated with changes to equipment, maintenance and calibration records. Annex C shows a typical check-list for many of the initial decisions.

NOTE The performance standard IEC 60079-29-1 includes certain minimum environmental tests. A summary of the environmental limits in these tests is found in Annex B. For apparatus complying with IEC 60079-29-1, testing may have been performed beyond the minimum limits. In this case, details can be determined from the certification documents.

6.1 General

In selecting flammable gas detection apparatus, account should be taken of environmental factors and requirements relating to the situation where it is to be used and the intended application. Regard should be paid to the safety of any personnel who could be involved, particularly if vapours are present. For guidance, see Clause 4. Account should then be taken of any features of the apparatus that may necessitate particular caution in its use and the interpretation of the output. Each of the various types of sensor has inherent limitations, as described in Clause 5 or in more detail in Annex A.

NOTE 1 This standard is not intended to discourage the use of apparatus using detection principles other than those described in 5.1 to 5.9 or to inhibit the development of new detection principles. However, it is of primary importance that the capabilities of the detection principle should be such that the performance of the apparatus is adequate for the intended application, and its use should be safe.

For apparatus for the detection of combustible gases, and related apparatus, there are two independent categories of test:

- Performance test – To ensure that devices are suitable for the detection of those gases and ranges they are designed for.

NOTE 2 Assessment of the flammable gas detecting apparatus against the performance requirements specified in IEC 60079-29-1 may provide a basis for judgement in appropriate circumstances.

- Electrical test – To prevent the ignition of explosive atmospheres by the apparatus itself.

NOTE 3 Conformance to explosion protection techniques in IEC 60079 series standards is required. This applies to all parts of the apparatus, including sensors for other gases. Testing, certification and marking should comply to the appropriate national regulations. This is mandatory for all applications.

WARNING – Normal zoning and the appropriate certification of apparatus is not valid in oxygen enriched atmospheres for example, welding gas mixtures.

6.2 Selection criteria

6.2.1 General criteria

6.2.1.1 Criteria of selection of appropriate gas detection apparatus

The following criteria are among those which should be considered when selecting appropriate gas detection apparatus:

- a) the gas(es) which the apparatus is required to detect, the range of concentrations of each gas which may be encountered, and therefore the range and accuracy required;
- b) the presence of potentially interfering gases;
- c) the intended application of the apparatus, for example area monitoring, personnel safety, leak detection or other purposes;
- d) whether the apparatus is required to be fixed, transportable or portable; For details, advantages, and restrictions of the three types, see Clauses 8 and 9;
- e) the type of sampling system; diffusion or aspirated. For details and restrictions of both types see 6.2.3 and 8.1;
- f) the classification of the intended zone(s) of use in accordance with national regulations;
- g) the environmental conditions that will be met in the area(s) of use, and comparison of this with the specifications of the proposed apparatus;

- h) the materials of the sensors and housings and their compatibility with the anticipated operating environment (corrosives; wind, rain, hosing etc.). Copper components should not be exposed where acetylene may be present because of the potential to form explosive acetylides;
- j) any features of particular apparatus that require caution to be taken in the use or interpretation of its output;
- k) time dependency and interaction with safety devices and alarms (see 6.2.1.2 and 8.7);
- l) calibration requirements including zero checks;
- m) occupational health and safety requirements for installers, operators, calibration and other maintenance personnel and other persons likely to be in the protected area.

Whatever type of sensor is selected, errors may result if:

- the apparatus is used to detect gases for which it is not calibrated;
- the gas sample is not conditioned to remove water vapour or other interfering vapours or gases, some of which may result in a negative response;
- variations in ambient conditions (without compensation) influence the response of the specific sensor type.

6.2.1.2 Delay times

A gas detection and measurement system should be so designed that the delay time of the whole system is less than the maximum delay time allowable for the provided application. At least, the following factors should be taken into account:

- a) potential release rate of flammable gas;
- b) delay time of the sampling system;
- c) response time of the sensor;
- d) delay time of data transmission lines;
- e) delay time of alarm devices and switching circuits;
- f) time taken for executive action devices, for example shut-down valves, to operate;
- g) time taken for any decisions and manual intervention, which is related to;
- h) degree of personnel training.

6.2.2 Gases to be detected by the apparatus

The gas detection apparatus is required to be sensitive to each of the gases that it is required to detect and also to be suitable for the range of gas concentrations that will be encountered. Reference should be made to the manufacturer's information to determine the suitability of particular detectors.

WARNING – Thermal conductivity, infrared, electrochemical, photoionisation and semiconductor sensors may be sensitive to certain non-flammable gases, in addition to the range of flammable gases which they are intended to detect, and some of the techniques are insensitive to some flammable gases. For example semiconductor sensors may be sensitive to water vapour or to combustion products in addition to flammable gases. Advice should always be sought from the manufacturer concerning the effect of interfering gases on particular sensors.

It is not normally possible to determine the concentrations of individual flammable gases in a mixture of flammable gases using the types of apparatus covered by this standard. In general, sensors of the types described in 5.1 to 5.9 respond to most or all of the flammable components of a mixture, without distinguishing between them.

Where a range of gases is likely to be present in an area to be monitored, it is recommended that a detector be selected that has been calibrated to the gas in that range to which it is least sensitive. However, care should be taken to ensure that the sensors so calibrated will remain adequately sensitive to the other gases likely to be present. If this is not practicable, then an alternative approach is to select separate sensors, calibrated to the different gases likely to be present.

When a mixture of gases of known relative concentration is to be monitored, it is recommended that this mixture is used for calibration, if at all practicable. When the composition of a mixture is unknown or if a range of gases are likely to be present in the area to be monitored, it is recommended that the sensor is calibrated to the gas to which it is least sensitive.

WARNING – Catalytic detectors have varying levels of sensitivity to different flammable gases. The ratio of response to different gases can change with time, particularly for methane or natural gas. If a range of gases is likely to be present in the area to be monitored, consult the manufacturer for recommendations on the most appropriate calibration gas. If methane is one of the gases to be detected, use a methane in air check gas or calibration gas (see 11.2).

Those parts of the gas detection apparatus that are located in, or may be taken into, a hazardous area should be certified for the gases that may be encountered. The certification should cover use of the apparatus in the appropriate gas group, IIA, IIB or IIC, and temperature class, according to IEC 60079-0. Gas group data on many individual gases are given in IEC 60079-20.

WARNING – Gas detection apparatus of the types covered by this standard are not normally designed or certified for use in oxygen enriched or deficient atmospheres, and their use in such atmospheres should be avoided. For example particular care should be taken where oxy-acetylene welding operations are being carried out in an area protected by gas detection apparatus; should an unlit oxygen enriched acetylene jet be accidentally directed at any of the gas sensors, an uncontrolled ignition could occur; oxygen enriched acetylene is a particularly dangerous gas mixture.

Some of the techniques (particularly catalytic) are not suitable for the detection of flammable gases in highly oxygen-deficient or inerted atmospheres.

In explosion protection applications where oxygen concentrations can significantly change, it is therefore necessary to have oxygen measurement. Typical measurements are made to:

- ensure the minimum oxygen concentration for correct functioning of apparatus for the detection and measurement of combustible gases and vapours;
- ensure the maximum oxygen concentration permitted is not exceeded;
- monitor any increase in oxygen concentration which may increase the upper explosion limit and may decrease the energy required for ignition;
- protect personnel.

The lower and upper flammable limits of combustible gas in air will vary with temperature, pressure and oxygen concentration. Normal variations in these ambient conditions should not significantly affect the performance of the apparatus. However, if larger variations of temperature, pressure or oxygen are expected, the manufacturer should be consulted, see the normal criteria in IEC 60079-29-1 (group II apparatus).

6.2.3 Intended application of the apparatus

6.2.3.1 Fixed apparatus and fixed systems

Fixed apparatus and fixed systems should be used where permanent gas monitoring in selected areas of a plant or other installation is required. These areas may be static as in manufacturing plant or mobile as in transport systems.

In general, fixed apparatus consists of sensors or sampling points that are located in the hazardous area, and associated equipment that may be located either in the hazardous area or in a non-hazardous area such as a control room. All parts of the apparatus or system are permanently installed.

According to the specific application, the suitability of the whole system has to be assessed, including the selection and the approximate number and placement of sensors or sampling points (see 8.2), the alarm levels and the response time. It may be appropriate to obtain advice from equipment manufacturers or a suitably trained person.

The fact that it is fixed permits the apparatus to be energised ultimately from mains power. However the use of a battery back-up system will increase the availability of the apparatus.

There are three main types of fixed apparatus that are commonly used.

- a) Apparatus having the sensor and control unit situated within the hazardous area. In this situation the sensor and control unit may be combined or supplied as separate items.
- b) Apparatus having one or more sensors separate from the control equipment. This type of apparatus usually consists of individual sensors in the hazardous area, connected to the associated control equipment in a safe area.

NOTE 1 This is the most suitable type for the majority of industrial applications, particularly if a rapid response is required.

- c) Sampling apparatus. This type of apparatus usually consists of one or more sampling points in the hazardous area, connected to a sensor by means of aspirated sample lines made of suitable materials which are compatible with the sample (see 8.4). It may be more suitable than types a) or b) where comparatively static process conditions apply and where conditions (environmental or accessibility) at the same point are unfavourable to the sensor, for instance there can be a wider temperature tolerance. Another advantage is that it can permit the electrical parts of the system to be located out of the hazardous area, in which case, apart from using flame arrestors where sampling lines pass from a hazardous to a non-hazardous area, specific hazardous area compliance may not be required. Such flame arrestors can consist of sintered metals, capillary holes, or other fine gaps, for operation. These devices may increase the response time, may be affected by corrosion, and may be prone to blockage by dust or condensation. This means specific examination and maintenance is required. Flame arrestors should be checked or certified to confirm that they are suitable for their application.

NOTE 2 Apparatus and systems of the kind described in c) above should not be confused with those for process control, which do not come within the scope of this standard.

Gas detection apparatus may be designed to produce any or all of the following:

- 1) indication of gas concentration;
- 2) audible and/or visual alarms;
- 3) outputs to initiate actions such as process shutdown and automatic safeguard actions, for example process control, ventilation, elimination of ignition sources, etc.

Where item 3) is required, additional hardware may be necessary.

Each installation should be considered in its own right, in consultation with the manufacturer and safety authorities and in compliance with any mandatory local safety regulations.

6.2.4 Transportable apparatus

Transportable apparatus should normally be selected for such purposes as monitoring temporary work areas ("hot" work) and areas where flammable liquids, vapours or gases may be transferred.

6.2.4.1 Portable apparatus

Portable apparatus should normally be selected for such purposes as leak detection, verification and monitoring of gas-free conditions, safety checks and similar applications.

Portable apparatus is frequently used in a simple diffusion mode. In such cases, where leak detection is involved or where the apparatus is also used for the detection of gas in confined spaces beyond the normal reach of the user, either a static sample probe, or a hand or mechanically aspirated sample probe will be necessary.

Other portable apparatus may have a continually-operating miniature electrical pump, normally drawing sample from the immediate vicinity of the apparatus, but capable of drawing sample via a sample line or probe for the above purposes.

Sampling probes are associated with transportable and portable apparatus, are usually short (in the order of 1 m) and rigid, however they may be telescopic and may be connected to the apparatus by a flexible tube.

Where a portable apparatus is, from time to time, likely to be exposed to gas concentrations greater than the lower flammable limit (LFL), care should be taken to select apparatus suitable for that purpose.

Care should be taken to avoid condensation of water or sample vapour in the apparatus and sampling line especially when cold apparatus is transferred to an environment with a higher ambient temperature.

6.2.4.2 Portability of the apparatus

Factors that are important in selecting portable or transportable apparatus include its size, weight and robustness, its power supply requirements, the type of indication required, and the visibility or audibility of any alarms.

6.3 Miscellaneous factors affecting selection of apparatus

6.3.1 Electromagnetic immunity

Some types of flammable gas detection apparatus are susceptible to external radio frequency interference which causes malfunctions such as apparent errors in calibration, zero drift and false alarm signals. Where such problems are anticipated, suitable apparatus, adequately protected against such interference, should be selected.

6.3.2 Intended zone(s) of use

Gas detection apparatus is normally used in classified areas (Zone 0, Zone 1 and Zone 2), with certified intrinsically safe apparatus to Ex ia being usable in all three, and certified flameproof apparatus to Ex d (for example) being usable in the last two. Both techniques are also subject to apparatus group (IIA, IIB or IIC) and appropriate temperature class (T1 to T6) for the substances to be detected (these parameters are tabulated in IEC 60079-20). However, this all applies to gas detection in normal air which contains approximately 21 % oxygen by volume, or mildly oxygen – depleted air. It does not apply to cases where there is significant oxygen enrichment.

For a description of system safety and apparatus response expected under deficient or enriched oxygen conditions, consult the instruction manual, or contact the manufacturer for a recommendation.

7 Behaviour of gas releases

7.1 Nature of a release

7.1.1 General

The extent and/or rate of build-up of a flammable atmosphere is mainly affected by the following chemical and physical parameters of the release, some of which are intrinsic properties of the flammable material, others are specific to the process or location. For simplicity, the effect of each parameter listed below assumes that the other parameters remain unchanged.

7.1.2 Release rate of gas or vapour

The greater the release rate the larger the extent and/or rate of build-up of the flammable atmosphere.

The release rate itself depends on other parameters, namely:

a) geometry of the source of release

This is related to the physical characteristics of the source of release, for example an open surface, leaking flange, etc.;

b) release velocity

For a given source of release, the release rate increases with the release velocity. In the case of a product contained within process equipment, the release velocity is related to the process pressure and the geometry of the source of release.

A significant release rate combined with a high velocity will generate a momentum jet which will affect the behaviour of the released gas at least in the vicinity of the source.

Gas escaping with high velocity (for instance, a leak from a pressurized line or container) will behave initially as a momentum jet directed away from the source of release. As the distance from the source of release increases, the momentum of the jet will decay until eventually the dispersion of the gas will be controlled by air flow and buoyancy effects and subsequently by gas diffusion.

c) concentration

The concentration of flammable vapour or gas in the released mixture influences the release rate.

d) volatility of a flammable liquid

This is related principally to the vapour pressure, and the heat of vaporization. If the vapour pressure is not known, the boiling point and flashpoint can be used as a guide.

An explosive atmosphere cannot exist if the flashpoint is significantly above the relevant maximum temperature of the flammable liquid. The lower the flashpoint, the greater the extent and/or rate of build-up of a flammable atmosphere will be.

Some liquids (for example certain halogenated hydrocarbons) do not possess a flashpoint although they are capable of producing an explosive gas atmosphere. In these cases, the equilibrium liquid temperature which corresponds to the saturated concentration at the lower flammable limit should be compared with the relevant maximum liquid temperature.

Liquids have to be taken into account when their temperature is above $(TF-x)$ K, where TF is the flashpoint and x is a safety margin. This safety margin is about 5 K for pure chemicals, but should be increased to 15 K for mixtures.

NOTE Under certain conditions, the mist of a flammable liquid may be released at a temperature below its flashpoint and still produce an explosive atmosphere.

e) liquid temperature

The vapour pressure increases with temperature, thus increasing the release rate due to evaporation.

The temperature of a liquid after it has been released may be increased, for example by a hot surface or by a high ambient temperature.

7.1.3 Flammable limits

The lower the LFL as a volume fraction of flammable gases or vapour in air, the greater will be the extent and/or rate of build-up of a flammable atmosphere. Given identical release rates, gases with lower LFL values will reach their ignition concentration more quickly than gases with high LFL values.

LFL and UFL both vary with temperature and pressure, but normal variations in these parameters do not appreciably affect the limits. A useful reference is IEC 60079-20.

NOTE Because LFL and UFL values are experimental, different countries specify different values for LFL and UFL, which have a legal standing. As two examples:

- NFPA 30 is a publication used within the USA,
- GESTIS is a publicly available database used within Germany.

7.1.4 Ventilation

An increased efficiency of ventilation usually reduces the extent and/or rate of build-up of a flammable atmosphere. Obstacles which impede the ventilation may increase the extent and/or rate of build-up of a flammable atmosphere. On the other hand, some obstacles, for example a bund, or walls or ceilings, may limit the extent and/or rate of build-up of a flammable atmosphere.

7.1.5 Relative density of the released gas or vapour

The behaviour of gas which is released with negligible initial velocity (for instance, vapour produced by a liquid spillage) will be governed by buoyancy and will depend on the relative density of the gas with respect to air.

If the gas is significantly lighter than air, it will tend to move upwards. If the gas or vapour is significantly heavier, it will tend to accumulate at ground level. The horizontal extent and/or rate of build-up of a flammable atmosphere at ground level increases with increasing relative density and the vertical extent and/or rate of build-up of a flammable atmosphere above the source increases with decreasing relative density.

NOTE 1 For practical applications, a gas mixture which has a relative density below 0,8 is regarded as being lighter than air (e.g. methane, hydrogen or ammonia). If the relative density of a gas or vapour mixture is above 1,2, it is regarded as being heavier than air. Between these values, both of these possibilities should be considered.

NOTE 2 Mixtures of high and low density gases with air will show less variation of density and, once mixed, they will not separate again; they can only become more diluted.

7.1.6 Temperature and/or pressure

If the gas or vapour prior to release is at a temperature and/or pressure significantly different from the ambient pressure and temperature, the absolute density of the release will be affected, and hence its behaviour, at least in the vicinity of the source.

A gas at high pressure escaping into the atmosphere may be strongly cooled as it expands adiabatically. Similarly an escape of compressed liquefied gas (e.g. LPG, or ammonia) will be cooled to its boiling point, well below 0 °C.

Any thermally induced flow (e.g. convection currents from hot or cold surfaces or plant or equipment), particularly if adjacent to a source of release, may affect the propagation, and hence distribution, of a gas/air mixture.

7.1.7 Other parameters to be considered

Other parameters such as climatic conditions and topography may also have to be taken into consideration.

If there is significant ambient air movement or the release is into enclosed spaces, then the above behaviour will be modified as described in subclauses 7.2 and 7.3.

7.1.8 Outdoor sites and open structures

In the case of outdoor sites and open structures, the dispersion of gas following a release may be affected both by the wind speed and by the wind direction. In open areas, the lateral spread of gas upwind of the release will be reduced, whilst downwind of the release it will be increased. This effect will be greater at high wind speeds. More complex air flow patterns will occur around buildings or other structures. In these cases, the wind direction may have a significant influence, and the possibility of gas accumulating in partially enclosed spaces, or in spaces with restricted air movement, should be considered. Where it is intended to install gas detectors in a major plant, the use of mathematical models of gas dispersion, or of scaled wind tunnel tests, may be appropriate at the design stage.

Local thermal effects may be significant in controlling air flow patterns and may, therefore, influence the dispersion of gas. For example large thermal gradients may be generated close to hot surfaces. In addition, the relative density of the gas will be affected by both the temperature of the gas itself and of the surrounding air.

7.2 Buildings and enclosures

7.2.1 General

Within buildings and enclosures the tendency for gases to form a hazardous accumulation following a release is generally greater than in outdoor locations. When a gas is released into an enclosed space, it mixes with the air in the enclosure to form a gas/air mixture. The manner in which this mixture forms will depend upon the gas release velocity, the location of the release, the gas density, ventilation, and any superimposed thermal flows. These factors should be taken into consideration in determining appropriate positions for sensors.

7.3 Unventilated buildings and enclosures

Theoretically, in the absence of any ventilation air flow and/or thermal effects, the release of a lighter than air gas will tend to form a layer of gas/air mixture extending from the level of the source of release to the ceiling. The release of a heavier than air gas will tend to produce a layer of gas/air mixture extending from the level of the source of release to the floor.

If the release takes the form of a momentum jet, this behaviour may be modified. For example if a jet of lighter than air gas is directed downwards from the source of release, then the layer of gas/air mixture may extend from the ceiling to a position below the level of the source of release. Similarly, if a jet of heavier than air gas is directed upwards from the source of release, then the layer may extend from the floor to a position above the level of the source of release.

NOTE If a potential source of a gas release is present in buildings or enclosures, then adequate ventilation should be provided.

7.4 Ventilated buildings and enclosures

The ventilation of buildings and enclosures is achieved by "natural means," "mechanical means", or a combination of the two.

NOTE When a release concentration has decreased to considerably less than the LFL (lower flammable limit), it will tend to move with the normal air flow due to the small difference in density between the gas mixture and the uncontaminated air.

7.5 Natural ventilation

Natural ventilation is the flow of air into and out of a building or enclosure through any purposely built or adventitious openings in its structure. Ventilation air flows are caused by two effects; firstly, any pressure difference across the enclosure created by wind and, secondly, buoyancy due to any difference in temperature (and hence density) of the atmosphere contained within the enclosure and the outside air. For natural ventilation due to the latter effect where the temperature in the building or enclosure is higher than that of the outside air an upward flow will tend to be produced. Conversely, if the inside temperature is below that of the outside air, a downward flow will tend to be produced.

The release of a gas or vapour into a naturally ventilated building or enclosure will tend to result in the formation of a gas/air mixture in a manner similar to that described in 7.3. However, in this case, the gas concentration in the mixture will be lower for a given release rate due to dilution by the ventilation air flow.

If a heavier than air gas or vapour is released into an enclosure in which natural ventilation produces an upward flow, then the gas/air mixture may extend above, as well as below, the level of the source of release. Conversely, if a lighter than air gas or vapour is released into an enclosure in which ventilation produces a downward flow, then the gas/air mixture may extend below, as well as above, the level of the source of release.

NOTE Further information on natural ventilation is given in IEC 60079-10.

7.5.1 Mechanical ventilation

Mechanical ventilation is the term used to describe air flow through an enclosure induced by mechanical means, i.e. fans. Ventilation air flows set up by mechanical means can be high (for example greater than 12 volume changes per hour).

The gas concentration within an enclosure ventilated by mechanical means will, in general, be much less than that resulting from a similar release into a naturally ventilated enclosure.

NOTE In case of very high gas concentrations (above LFL), or in the area above a flammable liquid with low flashpoint, an increased ventilation may lead to an increased volume of the explosive atmosphere.

In a well-designed ventilation system the whole volume within an enclosure is swept by the ventilation air flow. Where the geometry of the enclosure gives rise to regions of poor air movement or "dead spaces," a gas/air mixture may accumulate. Therefore, detectors should be sited in these spaces.

NOTE Smoke tracers may assist in identifying the air movement within an enclosure and the presence of any dead spaces where gas/air mixture may accumulate.

If a sensor is installed in the intake or exhaust duct of a mechanical ventilation system (depending on where the release might occur), then the alarm set point should be set as low as reasonably practical.

Some sensors use sintered materials as flame arrestors and the ability of an air/gas mixture to diffuse through the sinter to the sensing element can be adversely affected by very high air velocities that may occur in ducting arrangements. If this happens, additional shrouding of the sensor can help.

7.5.2 Environmental considerations

Environmental operational parameters should be included in the instruction manual of the intended apparatus.

Where environmental conditions are beyond specified values, the manufacturer should be contacted to ensure that the apparatus is suitable.

8 Design and installation of fixed gas detection systems

A fixed gas detection system should be capable of giving an early warning of both the presence and the general location of an accumulation of flammable gas, in order to initiate one or more of the following actions, either automatically or under manual control:

- a) safe evacuation of premises;
- b) appropriate fire-fighting and other emergency procedures;
- c) removal of hazard;

- d) shutdown of process or plant;
- e) increasing ventilation.

The consequences to the safety of personnel, and the economic effects of potential damage, following an undetected release should be of major concern. This should lead at the outset to consideration of integrity of the system, redundancy, integrity of power supplies, fail-safe operation, etc.

Therefore, it is of great importance that gas detection apparatus should be installed and used in such a way that only authorized personnel will have access to the functional controls of the apparatus.

A major consideration is the selection of the quantity, and the locations, of detector heads or sample points. Practically this must be done by consideration of a wide range of factors including industry standards and regulatory authority requirements, the local environment and safety, and therefore usually requires a wide range of expertise

8.1 Basic considerations for the installation of fixed systems

If the apparatus or any auxiliary components are installed in a hazardous location (i.e. 'classified' or 'zoned' area), they should be suitable for the area in which they are installed and so marked.

Three main types of fixed systems are commonly used.

- a) Systems consisting of remote sensors connected to the alarm and control equipment by electrical cables

These systems are the most suitable for the majority of industrial applications. A system of this type should, in general, be installed so as to be capable of continuously monitoring every part of the plant or other premises where flammable gases may accidentally accumulate. It should be capable of giving the earliest possible warning of an accidental release or accumulation of gas within practical limits of the system, for example as related to the number and location of sensors.

Remote sensors and stand-alone apparatus should be connected to their associated control and alarm equipment according to the national requirements for installation of electrical equipment. The sensors and any other parts of the system which are located in a hazardous area should incorporate an explosion protection technique covered by the IEC 60079 series of standards for the intended zone of use.

NOTE At excessively high and low temperatures the sensor may be operating outside the temperature range specified by the manufacturer and therefore may no longer comply with its electrical safety certification.

- b) Systems consisting of sampling apparatus

These systems are used when comparatively static process conditions apply, and rapid response is less important. The main advantage is that they can permit all of the electrical parts of the apparatus to be located outside the hazardous area, with only tubes filters, etc., inside it and a suitable of flame arrester at the interface. Where a system involving a single detection apparatus with timed sequential sampling of a number of sample points is installed, the interval in time between two successive samples being taken at any one sample point should be sufficiently short that a potentially hazardous accumulation of flammable cannot occur during the interval. The length of any sample tube and the sampling flow rate should also be such that a potentially hazardous accumulation of flammable cannot occur during the time taken for a sample to pass from the sampling point to the sensor. For this reason, sample tubes should be as short as is reasonably practicable.

c) Open path / Line of sight systems

These systems have special requirements, limitations and characteristics that do not come within the scope of this standard, (see also the note at the end of Clause A.3). Such systems usually employ an infra red technique, where the emitter and sensor are installed at opposite ends of a 'line of sight' path traversing an area. A mirror can be used on one side of the area so that the emitter and sensor can be adjacent on the other side, and other configurations are possible.

8.2 Location of detection points

IMPORTANT – The principal objective is that sensors and sampling points should be placed such that gas accumulations are detected before they create a significant hazard.

But there are other requirements:

Sensors and sampling points should be located in positions determined in consultation with those who have a knowledge of gas dispersion, those who have a knowledge of the process plant system and equipment involved, and safety and engineering personnel.

This determination should consider:

- a) the combination of sources of release with propagation effects (Clause 7);
- b) whether the sources of release can be inside our outside confining structures, buildings etc.;
- c) what can happen at access points such as doorways, windows, tunnels, trenches etc.;
- d) local environmental conditions;
- e) occupational health and safety;
- f) access for maintenance including calibration and verification, and protection of the system against operational hazards of the plant.

The decisions reached on the locations of sensors and sampling points should be recorded in a safety dossier for the plant (refer also 8.10).

8.2.1 General site considerations

Where it is necessary only to detect the escape of gas from within a given area, then sensors or sample points may be placed at intervals around the perimeter of the site. However, such an arrangement may not provide an early warning of a release. This arrangement should not be used alone if a release could cause a significant hazard to personnel or property within the perimeter itself.

Sensors or sample points should be located close to any potential sources of major release of gas, although to avoid nuisance alarms, detection points should generally not be located immediately adjacent to equipment which may produce inconsequential minor leakage in normal operation. In general, on open sites minor leaks may be dispersed without causing a hazardous accumulation.

Sensors should also be located in all areas where hazardous accumulations of gas may occur. Such areas may not necessarily be close to potential sources of release but might, for instance, be areas with restricted air movement. Heavier than air gases are particularly likely to flow like a liquid and to accumulate in cellars, pits and trenches if these are present. Similarly, lighter than air gases may accumulate in overhead cavities.

If there is significant ambient air movement, or if the gas is released into enclosed spaces, then the behaviour of gas is modified. The behaviour of gases following a release is complex and depends on many parameters. However, knowledge of the influence of these parameters is not sufficient, in practice, to predict the extent and/or build-up speed of a flammable atmosphere. The prediction may be improved by:

- 1) the application of generally accepted empirical rules developed by experts, based on their past experience;
- 2) on site experimentation to simulate and describe precisely the behaviour of the gases. This includes the use of smoke tube tests, anemometer readings or more detailed techniques such as tracer gas analysis;
- 3) numerical simulation of gas dispersion.

In general, sensors should be sited above the level of ventilation openings and close to the ceiling for the detection of gases lighter than air, and below the ventilation openings and close to the floor for the detection of gases heavier than air.

Where it is required to detect the possible ingress of gas or vapour into a building or enclosure from an external source, sensors should be sited adjacent to the ventilation openings. These sensors should be in addition to any required for the detection of releases within the building or enclosure.

If ceilings or floors are compartmentalized by equipment or other obstructions, sensors should be installed in each compartment.

8.2.2 Environmental conditions

Fixed apparatus, or more particularly their sensors, may be exposed to a very wide range of environmental conditions for very long periods of time. Great care should be exercised in the selection and location of this apparatus in relation to the likely environmental conditions applying in normal and abnormal use.

8.2.2.1 Adverse weather conditions

Sensors located on outdoor sites and open structures may be subjected to severe environmental conditions, and account should be taken of these conditions at all times. For example high winds may cause drift of the zero reading. High winds may even cause apparent transient loss of sensitivity during calibration due to dilution of the calibration gas being detected, if using the manufacturer's normal calibration equipment. For high wind applications, the manufacturer should be consulted about these points.

Great care should be taken in the location of sensors in exposed sites, and adequate weather protection measures should be provided for the sensor. Steam, driving rain, snow, ice and dust, etc. may also adversely affect sensors. Certain materials, although otherwise suitable for sample lines or weather guards, may deteriorate from sunlight or other environmental conditions.

Sensors located in buildings or enclosures are generally not exposed to adverse weather conditions.

8.2.2.2 Excessive ambient temperatures

All sensors, sampling points, and apparatus should be mounted in areas which ensure compliance with the manufacturer's operating temperature specifications.

Where there are excessively high or low ambient temperatures, the detector may be operating outside the temperature range specified by the manufacturer, and detection errors and reduced sensor life may occur. In addition, at both excessively high and low temperatures, the apparatus may no longer comply with its hazardous area certification.

For example the electrolyte in many electrochemical sensors operating at temperatures much below -10°C may be limited by freezing. Portable applications may get around this limitation by keeping the detector in a warm area when not in use.

In general, the positioning of gas detectors directly above sources of heat such as ovens and boilers should be avoided and a suitable position at an adequate height away from the source of heat should be chosen.

In tropical and subtropical applications, external sensors and apparatus should be shielded from direct sunlight, as this can raise equipment temperatures above 65°C even with ambient temperatures around 40°C . The normal maximum for hazardous area certification is 40°C and the maximum for performance with IEC 60079-29-1 is 55°C , unless otherwise specified on the certificate.

8.2.2.3 Vibration

Where vibration is expected, particularly for apparatus mounted on machinery, care should be taken to ensure that it has been designed to withstand vibration, or that suitable vibration isolation mountings are provided.

8.2.2.4 Use of sensors in corrosive atmospheres

Precautions should be taken to protect sensors from damage resulting from exposure to corrosive atmospheres (for example ammonia, acid mist, H_2S etc.). Particular care should be taken to protect wiring (and other components made of copper or brass) if ammonia can be present, as it can cause severe corrosion and electrical failures.

8.2.2.5 Mechanical protection

Sensors mounted in positions where they may be exposed to mechanical damage (e.g. from normal plant operations, or the use of mobile equipment such as fork lifts) should be adequately protected without impeding the free flow of air around them. If necessary, recommendations should be obtained from the manufacturer.

8.2.2.6 Electromagnetic immunity

Appropriate precautions, for example the use of screened cables, should be incorporated when installing the complete cabling system (including that to ventilation controls etc.) to ensure that the total system is adequately protected from the effects of electromagnetic interference.

NOTE Reference should also be made to applicable national regulations regarding electromagnetic compatibility.

8.2.2.7 Hosing down

The practice of "hosing down" a plant may cause severe degradation of gas sensors and contaminate sampling lines. It should, therefore, be avoided if possible. If it cannot be avoided, the sensors should be protected against this, without impeding the free flow of air around them. This can be a complex problem.

8.2.2.8 Airborne and other contaminants

Sensors should not be exposed to airborne contaminants which may adversely affect their operation.

For example, materials containing silicones or other known poisons should not be used where catalytic or semi-conductor sensors are installed.

Dusts, or wet, oily, or adhesive sprays and mists, or condensed droplets can block key items, such as the diffusion screens of sensors, or sample lines and their filters, causing loss of sensitivity or function. This is of even greater consequence if both wet and solid materials are present to form pastes. This contamination may require regular cleaning or similar maintenance. Sample extraction and special filtration may be required in extreme cases.

There are many examples where paint overspray, or deliberate painting has been responsible for failure of sensors. This requires some education of maintenance personnel.

Care should be taken to avoid water condensation on diffusion screens and in sample line(s). Where high humidity samples are involved, this can require heating of critical parts or deliberately removing condensed water in traps, coalescing filters etc.

There are particular problems where a vapour of interest can condense on (or the liquid can otherwise come into contact with) diffusion screens, filters, or sample lines. This type of contamination will lead to incorrect and misleading signals until the last trace of contamination is removed. This can be extremely dangerous. If this type of contamination is possible, the only solution may be to heat the components that come into contact with the sample.

8.3 Access for calibration and maintenance

Sensors and sample points should be readily accessible to permit regular calibration, maintenance and electrical safety inspection. It must be possible to access and fit all accessories or test equipment needed for these operations at the detection point.

Where the sensor location makes this difficult (e.g. where it is high and over machinery) a system of lowering the sensing point on a pulley system or swinging arm to gain access may be practicable. Obviously, the cabling or sample tubing must be flexible or pivoted to permit this arrangement. The arrangement should preferably permit the original sensor orientation to be preserved for calibration.

If it is impossible to achieve regular direct access to the sensor then, as a minimum requirement, some form of remote gas calibration facility should be provided.

8.4 Additional considerations for sample lines

Sampling lines are usually permanently installed in fixed installations. Even if they are made of a flexible plastic material they will usually be less flexible and harder to install than cabling. Consideration should be made at the time of installation that they may need to be replaced in the future, for instance if they become badly contaminated or damaged. Joints need to be accessible.

Sample lines should be as short as possible since the response time is determined by the overall length.

Filters may be used to protect the apparatus from dust and interfering or poisoning substances. Generally a particulate filter is needed at each sampling point so that its sampling line is kept clean internally. Additional devices are required for this purpose where mists may be sampled. Frequently additional filtration is provided at the sensor apparatus.

Filters will increase the response time.

The lifetime of filters is dose dependent (dust or interfering substance). This may shorten the maintenance intervals of the apparatus. For details refer to the instruction manual.

The flow rate through the sampling line should be monitored.

The material of the sample line(s) should be selected so as to avoid adsorption, absorption and, chemical reactions with the gas being detected. In addition, care should be taken to avoid dilution of the sample by leakage or diffusion of dilutant air, or gas, into the sampling line or combustible gas out of the sampling line.

Where water condensation can occur it may block the sampling line. Water traps may be needed at any low spots along the sample line length. This is particularly the case if the line runs through areas that can be cooler than the sampling point (e.g. air conditioned areas in hot humid climates). Alternatively, the line may be heated, as below.

Consideration should also be given to the effects of condensation occurring with high flash point liquids on sampling systems, as this will reduce the concentration in the sample and hence the reading. Subsequent samples with lower concentrations of the vapour will permit it to re evaporate, giving incorrectly high readings. To minimize this effect, heating of the sampling line may be necessary. In hazardous areas if this heating system is electrical it shall comply with the relevant regulations and standards. Steam or hot water trace heating may be an option.

8.5 Summary of considerations for the location of sensors or sampling points

The rationale for the selection of location of sensors should be formally recorded in the dossier (refer 8.1 and 8.10).

NOTE Reference may be made to IEC 60079-10 for further information on area classification and gas dispersion.

The following is a basic check list, based on earlier clauses, of factors which should be taken into account, in no particular order of priority, in determining suitable sensor locations. These include, but are not limited to, the following:

- a) indoor or outdoor site;
- b) potential sources of emission – the location and nature of the potential vapour/gas sources (for example density, pressure, amount, source temperature, and distance) need to be assessed;
- c) chemical and physical data of the potential gases/vapours present;
- d) liquids with low volatility need sensors near the potential source of release (and low alarm or action points);
- e) nature and concentrations of gas releases likely (for example high pressure jet, slow leaks, spillage of liquids);
- f) presence of cavities and jets;
- g) topography of the site;
- h) air movements;
 - 1) indoors: natural ventilation, mechanical ventilation, convection,
 - 2) outdoors: wind speed and direction,
- i) temperature effects;
- j) environmental conditions of the plant;
- k) location and number of personnel in the area;
- l) location of potential sources of ignition;
- m) structural arrangements (such as walls, troughs or partitions) which could allow vapour/gas to accumulate;
- n) prescribed locations;
- o) detectors should be installed so that they are not vulnerable to mechanical or water damage from normal operations; and
- p) locations should be such that sensors can be readily maintained and calibrated.

8.6 Installation of sensors

For the reliable operation of a fixed gas detection system each sensor should be placed in a suitable location according to its individual application, and as decided above.

However, inspection and maintenance, including recalibration with gas, need to be carried out periodically by trained personnel. Therefore, access for such operations also needs to be considered in detail during installation.

It is important that the instruction manual is read and followed.

In many cases, the orientation of the sensor may be specified by the manufacturer.

Adequate drainage and/or heating should be incorporated into the system design to minimize moisture and condensation in the apparatus, detector head and interconnecting cable/conduit system, or sampling tube.

Any potential flammable gases introduced into sampling systems should be vented in a safe manner.

Lubricate all threaded connections, but ascertain that the lubricant contains no substance (for example silicone) that might be deleterious to the sensors.

Sensors shall be connected to their respective control unit, as specified by the manufacturer (observing maximum loop resistance, minimum wire size, isolation, etc.), and use a cable, wire and conduit system, or other system suitable and approved for the purpose, area classification, and suitable mechanical protection.

If the user is not able to address these points the work should be carried out by the manufacturer or other competent person.

8.7 Integrity and safety of fixed systems

8.7.1 General

If the gas detector system or channels of a system fail or are removed from service, so that areas of the plant cannot be monitored sufficiently, additional measures may be required to preserve safety. Planning for such eventualities should happen before installation.

It is similarly essential that safety is maintained when the gas detection system, or a part of it, becomes inoperative during routine calibration.

Additional measures to preserve safety may include:

- a) signalling of gas detection apparatus faults;
- b) use of portable or transportable gas detection apparatus;
- c) increased ventilation;
- d) elimination of ignition sources;
- e) interruption of supply of flammable gases or liquids;
- f) switching-off of plants or parts of them; and
- g) duplication of the most essential sensors.

8.7.2 Redundancy in fixed systems

In general, a fixed system should be so installed that failure of individual elements of the system, or their temporary removal for maintenance, does not compromise the safety of the personnel and premises being protected. Duplication or triplication of remote sensors and control apparatus is recommended in all areas where continuous monitoring is absolutely essential. Devices that operate 'fail safe' should be used wherever possible.

8.7.3 Protection against loss of main power supply

Protection against loss of the main power supply should include:

- a) main power supply

The main power supply should be designed so that the unrestricted operation of gas detection apparatus and alarm functions are guaranteed.

Breakdown or fault of main energy supply should be detectable. Safety of the monitored area shall be preserved by appropriate measures.

The main power supply should have a separate circuit with specially marked fuse used only for the gas detection apparatus.

b) emergency power supply

If an emergency power supply is required to maintain the function of the gas detection apparatus, it should do so until the normal state of supply is restarted or the monitored area no longer requires monitoring. Any peripheral external power supply shall be suitable for the area for which it is to be used (both for environmental considerations and for the area classification).

Breakdown of emergency power supply should be indicated by an alarm signal.

It is strongly recommended that for indication of power and/or apparatus failure, contacts are used which are closed in the non activated state (fail-safe).

8.8 Timing of installation during construction operations

Sensors should be installed as late as possible in any programme of construction operations (i.e. the construction of a new plant, refitting or maintenance) but before the presence of gas or vapours in the system, so as to avoid damage to the sensors resulting in particular from such activities as welding and painting.

If already installed, sensors should be protected with an air-tight seal to avoid contamination during construction work, and should be clearly marked as being non-operational.

8.9 Commissioning

8.9.1 Inspection

The complete gas detection system including all ancillary equipment should be inspected prior to use to ensure that the design and installation has been carried out in a satisfactory manner, and that, where appropriate, the methods, materials and components used are in accordance with IEC 60079-0. Among the items to be inspected are the following:

- a) confirm electrical connections are properly tightened;
- b) check for sample-line leaks and proper flow;
- c) check for clogged or dirty flame-arresting systems;
- d) check the battery voltage and/or battery condition and make any required adjustments or battery replacements (according to the instruction manual);
- e) perform a test of the failure (malfunction) circuit(s).

A check should be made at this time to confirm that a full dossier of operating instructions, plans and records for the complete system have been supplied. This should have details of all sensing points (refer 8.2). The instructions should include details on use, testing, calibration and operation, and should include all manufacturers' instructions (refer 8.10).

8.9.2 Initial gas calibration

After installation on site each sensor should be calibrated according to the manufacturer's instructions, unless it carries currently valid factory calibration certification for the gas of interest. Calibration should only be carried out by a suitably trained and competent person.

After the initial gas calibration, fixed systems should automatically revert to the monitoring mode after a pre-determined interval without further adjustment. Alternatively, during calibration, the apparatus should produce a special (e.g. 'maintenance') signal to prevent the output from being mistaken for a normal measurement.

Where a number of gases are likely to be present, reference should be made to the additional precautions described in 4.3.2.1 and 6.2.2.

To ensure correct operation, it is essential to carry out both inspection and recalibration periodically.

8.9.3 Adjustment of alarm set points

In the case of detection apparatus only indicating up to the lower flammable limit, the alarm set point (or the lowest set point, where there are two or more) should be as low as possible commensurate with the need to avoid false alarm signals.

This might need frequent review during the early stages of operation of a new plant or gas detection system.

Adjustments should be carried out in accordance with the manufacturer's instructions.

8.10 Operating instructions, plans and records

Instructions on the use, testing and operation of fixed gas detection systems should be made available and placed in the system dossier.

For maintenance and record purposes, plans of the installation should also be provided and put in the dossier. The locations of all parts of the system (control units, sensors and sampling points, junction boxes, etc.) should be shown together with the routes and sizes of all cables, wires and sample tubes. Junction box and distribution cable diagrams should also be included.

It is extremely important that the equipment manufacturer's installation manual be read thoroughly, and the instructions followed completely. Again a copy of this should be in the dossier.

These records should be updated when any changes are made to the installation.

Routine tests of the combustible gas detection system is an extremely important factor affecting the reliability of the individual units. Optimum system performance and reliable operation will only be achieved through a defined program of comprehensive tests.

All types of gas detectors will require periodic recalibration using appropriate calibration gases. Where sensors are used that have definite service lives and/or susceptibility to poisoning (e.g. catalytic, electrochemical, semi-conductor) regular recalibration, or at least response checking, will be required. The required frequency may be specified by regulations of the responsible authorities. In most cases advice or recommendations can be obtained from the manufacturer. Ultimately it will depend on the severity of the application, and is best determined by starting a process of regular frequent checks and logging the results (amount of adjustment required etc) in the dossier. Periodic review will enable the most desirable interval between calibrations and/or response checks to be found. If different intervals are defined, the shortest time period should be taken.

The detection system should be frequently reinspected by a competent person. The inspection should be in accordance with the instructions of the manufacturer and the specific requirements of the application. A visual inspection of all units of the gas detection system should be carried out and the test and alarm functions should be checked. Special attention should be taken to look for contamination (e.g. dust or soil) and condensation of water or solvents in sampling systems and at the sensor locations.

Where sampling systems are used, the sample lines should be checked for contamination and inwards leakage. An easy way to do the latter is to apply calibration gas via a bladder, or otherwise at atmospheric pressure, at the sample point (DO NOT USE PRESSURE) and see if a similar result is obtained as in the normal calibration.

The manufacturer's operational instructions should be followed with regard to:

- periodic cleaning of filters, sensor windows etc.;
- assembly of required materials, for example auxiliary gas for some devices;
- safe operation of the system.

The results of all inspections should be recorded in the dossier.

9 Use of portable and transportable flammable gas detection apparatus

9.1 General

In Clause 8 it can be seen that there are many skills required in designing and creating an installation for fixed gas detection apparatus.

Each time a portable or transportable gas detection apparatus is used, its user is also essentially carrying out many of the same important functions in creating a temporary installation. However, the user will generally not have all the skills.

There are particular additional problems where users hire or borrow portable or transportable apparatus of this type. Relevant parts of Clause 6 may not have been properly applied. The maintenance and calibration history may not be known and the user may be unfamiliar with the particular apparatus.

Personnel responsible for users of portable and transportable apparatus essentially have two options. These are:

- a) To give personnel required to use portable or transportable gas detection apparatus proper training in its use, which would include Clauses 4 and 10, the rest of this clause, the relevant part of Clause 5 or preferably Annex A, and to train on and provide ready access to the operating instructions of the particular apparatus.
- b) To adopt the minimalist approach described as "read and run" in 9.3.9, following basic training on the particular apparatus and on any personal safety precautions relating to the particular application and any toxicity. Checking, calibration etc should then be done by others.

The various types of portable and transportable gas detection apparatus may be used in a variety of ways according to their particular design and specification. An important point is that they should never be used without additional precautions and training where significant amounts of gas is actually known to be present, particularly if option (b) is taken. The necessary steps to remove the gas should have been taken already.

NOTE There are certain applications where gas is always unavoidably present, such as in coal mines. Special training is required for such applications.

Small, hand-held apparatus may be used for leak-detection or spot checks, while larger portables, some with visual and/or audible alarms, may be used in multi-role mode so as to include leak detection, spot checking and local area monitoring functions, according to the particular needs of the user.

Transportable apparatus is intended for use for temporary area monitoring in locations where there is a probability of generating potentially flammable gas or vapour mixtures, for example during the loading or unloading of fuel or chemical tankers or where temporary "hot work" (in connection with maintenance activities) may be in progress in classified hazardous areas under the authority of a gas-free certificate. Transportable apparatus is not intended to be hand carried for long periods of time, but is intended to be in place for periods of hours or more.

Due to their very nature, portable and transportable apparatus may encounter a wide range of climatic, handling or more generally environmental conditions. Thus, the user should pay particular attention to the actual conditions imposed on an apparatus and assess that it is designed or protected so as to meet these conditions. This applies not only its use, but also when it is not being used, for instance mechanical damage, vibration when it is being transported, or excessive temperatures experienced on the back shelf of a parked car in the sun.

Routine testing of the combustible gas detection apparatus is an important factor affecting reliability. Optimum system performance and reliable operation will only be achieved through a program of tests. The frequency of the tests will depend on the effects of possible poisoning and aging on the type of sensor used (see Annex A) but otherwise can only be determined by experience of the particular application.

9.2 Initial and periodic check procedures for portable and transportable instrumentation

Due to the fact that portable and transportable instruments are generally not used continuously, initial and periodic check procedures are of the utmost importance to ensure that the apparatus is in a proper state of operation. A distinction is drawn between field checking (response checking) where no adjustment is made by the user, and recalibration where adjustment is made when necessary, although they use similar equipment. This is more a case of responsibility. The manufacturer's instructions for these checks should be precisely followed.

For safe and reliable operation of gas detection apparatus, recalibration, inspection and maintenance should be carried out periodically by a competent person. This work may be carried out by the user, the manufacturer of the apparatus or a sub contract service engineer.

9.2.1 Inspection and field-check (response check)

Inspection and field-check are intended to verify that the apparatus is in a working state. It is recommended that it is done by personnel actually operating the apparatus, and is strongly recommended that it is performed before each day of use, particularly if the apparatus has catalytic, electrochemical, or semiconductor sensors and is being used under arduous conditions.

NOTE 1 The instruction manual of portable apparatus complying with IEC 60079-29-1 is required in Subclause 4.4 of that standard to provide a method for performing a functional check with gas before each day of use.

NOTE 2 In critical cases where a permit to work is given as the result of a gas test, it is recommended that a response check is performed afterwards, and that the result of both the gas test and the response check are logged.

A simple sequence of inspections may include the following:

- 1) checking the battery voltage and/or battery condition;
- 2) allowing adequate warm-up time;
- 3) checking for sample-line leaks and proper flow in aspirated apparatus;
- 4) checking that a zero reading is displayed when operated in clean air (see note below);
- 5) performing a response check.

The last two of these may be performed as follows:

Place the detector head (integral or remote) or the sampling line in an atmosphere free of combustible gas, aspirate a large enough sample to purge the lines (applicable only to apparatus with sampling lines). If a significant deviation from zero is observed (but see note below), the apparatus should be recalibrated (see 9.2.2). Some instruments have an automatic zero check which will do this adjustment.

NOTE 3 Although there should be no measurable amount of combustible gases in clean air, and therefore a combustible gas sensor should read zero, this is not necessarily true for other sensors that may be incorporated in the same instrument: Oxygen sensors should read 20,8 or 20,9 % v/v under these conditions. There are approximately 360 parts per million of carbon dioxide (more in heavily built-up areas) which should give appropriate readings (e.g. 0,03 or 0,04 % v/v CO₂). Also in built up areas, there may be detectable amounts of CO.

The response (sensitivity) of the apparatus should be checked using the field calibration kit recommended by the manufacturer and performed with a known gas mixture which will give a response from all the sensors present. The user should know or should be instructed what reading(s) should be obtained. If the test results are not within ± 10 % of the anticipated result, the apparatus should be recalibrated (see 9.2.2).

NOTE 4 For catalytic sensors the mixture should contain at least 10 % by volume of oxygen.

NOTE 5 Very reactive gases like fluorine, hydrogenchloride or ozone are not suitable to be used within calibration gas mixtures for field checks.

For alarm-only apparatus, a test gas concentration should be applied which is equal to 5 % LFL above the highest alarm set point of the apparatus. All alarms should actuate during this test. If an apparatus fails this procedure, and suggested corrective action does not solve the problem, the apparatus should be recalibrated (see 9.2.2).

9.2.2 Routine checks and recalibration

Portable and transportable apparatus should be regularly recalibrated in a suitable workshop by a competent person. Any apparatus that is used infrequently should, nevertheless, be regularly inspected, and calibrated, so that it may be available for immediate use when required. This should be done in accordance with the manufacturer's instructions and typically may include:

- a) resetting of the mechanical zero of analogue meters;
- b) checking the tightness of all electrical connections (remote detector head, power supply etc.);
- c) allowing adequate warm-up time;
- d) checking for sample-line leaks and proper flow;
- e) checking for clogged or dirty flame-arresting systems;
- f) checking the battery voltage and/or battery condition and making any required adjustments or battery replacements;
- g) performing a test of the failure (malfunction) circuit(s);

- h) testing the alarm circuits;
- i) recalibrating by adjusting to a zero reading when operated in clean air and the correct value when a known calibration gas is applied. This may be done as follows:

Place the detector head (integral or remote) or the sampling line in an atmosphere free of combustible gas, aspirate a large enough sample to purge the lines (applicable only to apparatus with sampling lines). If a deviation from zero (see note in 9.2.1 for other gases) is observed it should be recorded and then adjusted to zero. Some apparatus have an automatic zero check which will do this adjustment.

The response (sensitivity) of the apparatus should be checked using the recalibration kit recommended by the manufacturer and performed with a known gas mixture which will give a response from all the sensors present. The concentration of combustible gas should preferably be chosen to give a reading between 25 % and 75 % of the full scale. This reading may also be specified by the manufacturer. If a deviation from the correct value is observed it should be recorded and then adjusted correctly. Some apparatus have an automatic sensitivity adjustment, and will only do this correctly with the specified gas

NOTE 1 For catalytic sensors the mixture should contain at least 10 % by volume of oxygen. In some modern multi-gas apparatus the gas specified by the manufacturer may have a known oxygen concentration above this value, and known concentrations of some toxic gases. This is used to simultaneously recalibrate all its sensors.

NOTE 2 Very reactive gases like fluorine, hydrogenchloride or ozone are not suitable to be used within calibration gas mixtures for field checks.

For alarm-only apparatus, a test gas concentration should be applied which is equal to 5 % LFL above the highest alarm set point of the apparatus. All alarms should actuate during this test. If not, the apparatus should be recalibrated.

The records of these checks may be used for long-term analysis for determining an optimum frequency of recalibration.

9.2.3 Maintenance and recalibration

Maintenance procedures should be undertaken only by qualified personnel trained in the operation, maintenance, and repair of combustible gas detection apparatus. If the maintenance facility is not adequately equipped and/or qualified personnel are not available to perform the manufacturer's recommended checkout and maintenance procedures, the user should return the apparatus to the manufacturer or other qualified outlet of repair. In the case of certified explosion-protected apparatus, the manufacturer should be consulted with regard to replacement parts.

For portable and transportable gas detection apparatus, it is important that the whole unit should be removed to a non-hazardous location for inspection and maintenance.

After any defective functions are corrected (repaired or replaced in strict accordance with the manufacturer's instructions), a full maintenance and recalibration procedure should be conducted.

Defective units should be either:

- returned to the manufacturer; or
- returned to a repair agent authorized by the manufacturer; or
- repaired in special workshop set up by the user for gas detector maintenance.

The results of maintenance and recalibration should be recorded in the dossier.

9.3 Guidance on the use of portable and transportable apparatus

9.3.1 Electrical safety in hazardous atmospheres

Portable and transportable apparatus should have a type of electrical protection appropriate for the zone of use. During use, portable and transportable apparatus should not be transferred from a zone of lower risk to a zone of higher risk unless it is suitably protected for the higher risk. Additionally, the apparatus group and the temperature class should be appropriate for all gases and vapours in which the apparatus may be used (see IEC 60079-20).

9.3.2 Safety of personnel

When about to work in a hazardous area it is necessary to specifically check on the potential toxicity of the atmosphere and the likely origin of any oxygen deficiency with the plant Safety Officer, Industrial Hygienist, or equivalent, particularly if confined spaces are involved. (see also Clause 4),

Oxygen deficiency may be due to the presence of toxic amounts of some other substance.

Some flammable gases (for example ammonia, hydrogen sulphide) and almost all vapours are also toxic and even lethal at very low percentages of LFL.

If the combustible gas apparatus is also equipped with high sensitivity sensors for specific toxic gases, it should be realized that they will usually not detect other toxic materials.

Gas detecting apparatus on its own may not be sufficient protection if toxic substances are likely to be present. In some instances an appropriate respirator and /or other devices may be needed as well.

Switch on the apparatus, allow it to warm up as necessary, and perform any fresh air checks (see e.g. 9.2.1) in a safe area but as close as practicable to the ambient conditions in the area to be monitored.

When entering the potentially hazardous area the user should frequently observe the readings on the apparatus. The user could be entering an already dangerous situation and may need all the warning they can get.

9.3.3 Spot tests and sampling

The apparatus will only give a reading for the location where the reading is being taken, or the location of the end of a sampling line, if used. A hazardous atmosphere may be building up a few metres from the sampling point. Therefore many gas tests must be done all around the intended area of work to ensure that no pockets of hazardous gas or vapour are present in the work area.

If vapours are likely to be present, some of the tests should be done a few millimetres from the floor, including all nearby low spots, using an extension probe or sample line if necessary. These tests might detect a small problem (e.g. from a minor liquid leak) at an early stage.

NOTE Only sample lines recommended by the manufacturer should be used (see notes on adsorption and chemical reactions in 8.4).

Similarly if light gases (e.g hydrogen, methane, ammonia) are likely to be present, some tests should be done near the ceiling or at least as high as practicable

The readings are only valid for the time they are taken. Circumstances change. Frequent readings are recommended, particularly if liquids could be involved and the temperature is rising.

Sample probes should be made of non-conducting material, and probes and lines should be kept dry. If there is any likelihood of coming into contact with mains-operated equipment.

9.3.4 Sampling above liquids

When sampling vapour above a liquid, care should be taken to avoid the sample line or sensor from coming into contact with the liquid, since this may block the gas entry to the apparatus, could damage the sampling system or sensor, and cause erroneous readings. Use a hydrophobic filter or equivalent where there is danger of drawing water into the detector. A probe with side entry and a solid tip can help to avoid drawing liquid in.

Once an apparatus or its accessories have been contaminated by liquid it must be regarded as unusable until the contamination has been completely removed.

9.3.5 Avoidance of condensation

When taking a portable apparatus from a cool environment to a warm environment, it is important that time is taken to allow the apparatus temperature to rise sufficiently to avoid vapour condensation which may cause contamination and/or incorrect readings.

Saturated steam may physically block the flame arrestors of certain types of gas sensor, so as to make them inoperative, and care should be exercised accordingly.

9.3.6 Poisoning of sensors

If the portable apparatus is of the multi-gas type containing sensors for the detection of toxic gases at low concentrations then calibration with some toxic gases, typically hydrogen sulphide, ammonia and chlorine, may cause inhibition of some flammable gas-sensing elements, particularly catalytic devices. Only use the test gases and calibration procedure stipulated by the manufacturer. It is recommended that if in normal use an alarm is given for any of these gases, the combustible sensor should be checked before it is further used.

If there is a chance of sensor 'poisons' (such as silicones, leaded petrol, acids, etc) being in the environment, the sensitivity of a catalytic combustion, electrochemical or semiconductor apparatus must be checked at frequent intervals (see 9.2.1).

9.3.7 Changes of temperature

When temperatures are rising, and vapours of liquids could be involved, gas testing should be frequent in view of the fact that vapour concentration could possibly double for each 10° rise in temperature.

9.3.8 Accidental damage

If a portable or transportable gas detection apparatus is dropped or otherwise damaged, it could have affected its explosion protection and/or performance. It should immediately be taken out of service for inspection, for any necessary repairs and for re-calibration, before re-use.

9.3.9 Minimalist operation, the “Read and run” concept

The safety margins are increased if small changes in readings are observed, rather than only relying on alarms that are always set some way up the scale.

Without extensive training, the user should not be put in a position to be gas testing where significant amounts of gases or vapours are actually present or expected.

Accuracy is not important as long as the apparatus will respond to a response check: The user is not to be expected to make a measurement, the intention is just to detect gas.

The user working in a hazardous location may not be fully familiar with gas surveying or the toxic nature of the environment. In such cases the advice to the user is to employ the ‘Read and run’ concept with consideration of local permitting practices.

Under this concept the basic operations are as follows:

- a) Observe the readings in clean air, as close as possible to the conditions that are going to be encountered at the point where the sampling will take place, particularly with regard to atmospheric temperature and humidity.
NOTE Altitude is also important; a change of 100 m in altitude can change an oxygen reading.
- b) Adjust the apparatus to its proper clean air readings. Or, if this is not allowed or not practicable, write down the clean air readings obtained.
- c) On going to the area where the tests are required, if there is any indicated change from the clean air reading, this is a ‘positive reading’.
- d) If you get such a positive reading **GET OUT**, that is ‘**Read and run**’.
- e) Then inform the responsible person, who may then carry out a proper survey by experienced personnel, taking proper precautions.

10 Training of operational personnel

10.1 General

Training should be provided for those maintaining, using or interpreting the results from gas detectors. A distinction is made between ‘Operator’ training for those using portable equipment or monitoring fixed apparatus, and ‘Maintenance’ training, for the sake of clarity and for the fact that users of the equipment generally will not be responsible for its maintenance. It is important to establish these roles at a very early stage.

However there is training in fundamental limitations of the environment and equipment, and essential safety training, for all personnel who could themselves go, or are responsible for sending others, into the hazardous areas.

Training may be done in-house by knowledgeable persons, or by vendor assisted training sessions.

Vendor literature is essential, and should be obtained and made available to these persons.

The training should also reflect the actual work environment and the responsibilities of the personnel concerned.

Periodic refresher training is strongly recommended.

Records of all training should be kept for a defined time span.

NOTE Some national regulations require training to be done by 'competent persons' as defined in those regulations, in a national training framework, or in national standards. Competency-based training of this type requires, in addition to instruction and practical hands-on experience, a formal assessment of each trainee by a qualified 'assessor' (who can be the competent trainer)

10.2 General training – Basic limitations and safety

For general training it is suggested that those parts of Clause 4 relevant to the site or application can be used as a basis, together with those sections of the vendor's literature relevant to the function of the personnel concerned.

Certain minimum information on limitations should always include:

- a) Flammable (combustible) gas equipment will only detect gases and vapours that are present in the vicinity of the detector (or in the line of sight of open path apparatus).
- b) It will only detect those vapours that do not condense at the temperature of the detector or its sampling equipment (where applicable).
- c) Where liquid flashpoints are well above ambient temperatures vapours can only exist at low percentages of LFL.
- d) Flammable gas equipment will not detect combustible liquids as such, or combustible mists, dusts, or fibres.
- e) Many types of flammable gas equipment have varying sensitivity to a whole range of gases. If the gas detected is not the gas on which the apparatus is calibrated, the reading will indicate upscale, but may not be correct.
- f) Erratic indications may indicate apparatus malfunction or some atmospheric disturbance. Where doubt exists, a check should be made with a second apparatus and/or the apparatus should be rechecked under controlled conditions before its continued use.
- g) The occasional or continuous presence of low concentrations of the gas of interest will produce indications that could be mistaken for zero drifts. In case of doubt, the apparatus should be rechecked using clean air.
- h) If off-scale readings in either direction are observed, It should be assumed that a potentially explosive atmosphere is present until proven otherwise (e.g. by checking with a second apparatus, applying clean air and then rechecking, etc).
- i) Some flammable gases and all vapours (except water) are toxic at low levels of concentration. The potential toxicity should be known, and necessary precautions taken.
- j) In confined spaces there may be oxygen deficiency, which in turn might be due to toxic substances. Confined space entry is a specialised operation and requires specialist training.
- k) If probing or sampling via a tube from confined spaces, a severe oxygen deficiency can cause the more common types of flammable (combustible) gas equipment to misread.

10.3 Operator training

In the simplest case for users of portable equipment, there is the training for “Read and run” operations (see 9.1 and 9.3.9). This, however, requires that the person directing the operator is sufficiently well trained to be responsible for the safety of the operator in the particular circumstances under which the operator will, or could possibly, be working.

For advanced users of portable equipment and for operators using fixed systems, the training should be designed to ensure understanding and familiarity of equipment, the working environment and the system. It should advise and show operators how to make visual and functional checks, and whom to contact in the event that the apparatus is suspected of malfunctioning.

It is particularly important that operators should have instructions to be followed in the event of a gas alarm.

Periodic (e.g. annual) refresher training should be given. This is vital in situations or applications where alarms seldom occur.

Instructions should be drafted prior to installation of a fixed system or the introduction of portable detectors to cover actions to be taken in the event of alarms, other safety considerations, and the personnel who should be informed if a malfunction is suspected.

10.4 Maintenance training

Maintenance training should be designed for those charged with inspections, maintenance and calibration. In addition to providing all information necessary to perform these tasks, it should include some understanding of detector function etc. Vendor literature is essential.

11 Maintenance, routine procedures and general administrative control

11.1 General

Routine maintenance of any flammable gas detection system is an extremely important factor affecting the reliability of the units. Optimum system performance and reliable operation will only be achieved if there is informed management, producing a responsible and practical programme which yields complete, dedicated maintenance on a high priority level.

Management of such a program depends on setting responsibilities for the various aspects (e.g. who is supposed to do field checks, who is supposed to inspections and re-calibrations, and who is responsible for maintenance), and then ensuring that the personnel concerned are adequately trained and periodically retrained. Part of this management responsibility is setting operational limits (e.g. determining acceptable tolerances on field checks that are to be permitted before re-calibration becomes mandatory, determining the frequency of regular re-calibrations, the frequency of maintenance etc).

Records should be made and filed for all inspections, verifications, tests and work done on the detection system. An excellent means of keeping records for the system which also aids in keeping abreast of the required maintenance tasks, such as calibration, is the use of certain computer programmes. In the simpler cases, refer to Annex D for a typical maintenance record.

Gas detection apparatus should be individually identifiable. Portable and transportable apparatus should be marked with an identification of the calibration date and, according to the control system employed, the length of time to the next re-calibration.

Flammable gas detection apparatus or systems vary in application from portable units taken to sites where gas/air atmospheres are expected to be present, to fixed systems which may rarely sense a gas/air mixture in their working lifetime.

Inadequate maintenance, incorrect zero adjustment and, in portables, deteriorated batteries are all causes for errors in gas detection. It is important to remember that errors and failures in gas detection apparatus or systems may not be self-evident, and therefore gas detection should be only part of the overall strategy for plant and personnel protection.

The reliability of the measurement depends on the use of test (calibration) gas, essentially duplicating its entire function. All types of apparatus whether portable, transportable or fixed (including both point and open path types) should be checked at regular intervals with the test gas recommended by the manufacturer.

When it is necessary to detect the presence of several gases mixed with air, the sensitivities to these gases should be checked periodically with appropriate test gases.

An in-depth calibration should be performed regularly by the plant instrument maintenance personnel, or their equivalent, on every portable apparatus or fixed sensor (detector head). Records should be maintained for each portable apparatus or detector head.

The time intervals at which these procedures should be carried out will depend upon many factors including: the nature of the apparatus, i.e. whether portable, transportable or fixed; the detection technique employed; the prevailing environmental conditions at the installation; the previous history of performance; and reliability in the application concerned.

Regarding calibration, gas detection apparatus should be:

- 1) regularly inspected for possible malfunctions, damage or other deterioration;
- 2) calibrated in accordance with the manufacturer's instructions, using the recommended test kit/equipment. (see 8.10);
- 3) If fixed, calibrated on commissioning and tested/re-calibrated at defined intervals thereafter; For new installations it may be prudent to carry out such procedures frequently at first (perhaps weekly), increasing the time intervals (to, perhaps, monthly) as confidence grows with experience in the installation concerned, on the basis of the maintenance records;
- 4) if portable, the field check (response check) in 9.2.1, or the re-calibration in 9.2.2 needs to be frequently done. In arduous or unknown situations or where the apparatus is not frequently used, this should be done immediately before each occasion of use. Where "gas-free" or "permit to work" certificates need to be issued, there is a strong argument in doing at least the field check after use, and recording this result as well on the certificate. In less demanding situations, the guidance in (item 3) above should be used;

NOTE 1 The instruction manual of portable apparatus complying with IEC 60079-29-1 is required in 4.4 of that standard to provide a method for performing a functional check with gas before each day of use.

- 5) if several gases are likely to be present, detectors should be calibrated to the gas for which they are least sensitive.

NOTE 2 It is acceptable to use a calibration gas, different from that monitored, provided that an appropriate correction is made, so that the detectors when calibrated give the correct response to the monitored gas. However, if methane is one of the gases that could be detected, use methane in air calibration gas.

To ensure that hazardous area certification is not invalidated, any repair or maintenance that involves the explosion-protection of the apparatus should not be carried out without full instructions and drawings from the certificate holder. Preferably the equipment should be returned for repair to the certificate holder.

NOTE 3 In many countries, the legal liability for maintenance of certification on apparatus may rest with the owner/user.

NOTE 4 The requirements included in IEC 60079-19 should be accepted.

Apparatus awaiting re-calibration or maintenance should be kept separately from apparatus awaiting return to service after such operations.

Spares may deteriorate in storage owing to mishandling or age and should always be tested before use. In particular, care should be exercised with optical surfaces.

11.2 Operational checks

The following inspections and tests should be made on a regular basis as specified below to maintain the reliable operation of the gas detection system.

NOTE If the status of an apparatus is not known, it should be checked prior to operation.

11.2.1 Fixed systems

a) Regular visual inspection

Regular inspection of the control panel should be made (for example one per shift). Records made of each check, including any problems, should be signed, dated and filed. Problems found should be corrected promptly.

b) Regular functional verification

Regularly, verification of the control and alarm panel should be made using test switches to ensure that lights, alarms and electronics are operating normally. This functional check will vary depending on the unit used. Problems found should be corrected promptly.

c) Regular calibration and system operation test

This test is of vital importance to the ongoing reliability of the system. In the case of sensor-based systems it includes subjecting each head to the calibration gas, thus allowing a complete loop check of the electronics and the sensor by maintaining accurate records of information about system patterns, particularities, component life, etc. By doing so, potential problems can be averted before they develop.

In the case of systems using sampling tubes this translates into regular calibration checks of the central analyser(s) and of derived alarm circuits. Periodically the integrity of the sample system and each individual sample line should be checked by applying the test or calibration gas, at atmospheric pressure, directly to the sample point and verifying that the same result is obtained as when applying the same gas to the analyser(s). In this the gas must not be pressurised: Easy means of doing this include the use of thin plastic bags or bladders of the gas, applying the gas from some sort of flow regulator at a higher flow than the sampling rate, with a blow off to atmosphere for the extra flow, or the use of a demand regulator.

NOTE This is the most important test to be made on the system and should be made on all sites at the time of installation and again at regular intervals. Guidance may be obtained from the manufacturer.

- d) Complete the maintenance records. Refer to Annex D for a typical maintenance record.

11.2.2 Portable and transportable gas detection apparatus

a) Visual inspection

- 1) Check the apparatus for abnormal conditions such as malfunctions, alarms, non-zero readings, etc.
- 2) Ensure that the detector head assembly is free of obstructions or coatings which could interfere with the gas or vapour reaching the sensing element. Ensure that the sample drawn is correct for sample-draw systems.
- 3) For sample-draw systems, inspect flow lines and fittings. Cracked, pitted, bent or otherwise damaged or deteriorated flow lines or fittings should be replaced with those recommended by the manufacturer.

b) Response (sensitivity) checking

This should be, at least, the field check (response check) in 11.2.1, or the re-calibration in 11.2.2. Either of these consists of:

- (i) Ensuring that the apparatus indicates zero when zero gas is present; temporarily isolating the sensing element if necessary.
- (ii) Applying a known calibration gas to the detector head, following the manufacturer's instructions.

The difference between the field check and re-calibration is that in the former, some tolerance in readings is given by the person managing the gas detection and adjustment is not made when the calibration gas is applied, although a zero adjustment may be permitted. This check should ideally be performed by the operator.

In the case of a re-calibration, this should be done on a planned regular basis and also if a field check is outside the permitted limits. The responsibility for this may be placed with maintenance personnel.

- c) Complete the maintenance records. Refer to Annex D for a typical maintenance record.

11.3 Maintenance

11.3.1 General

Maintenance operations should not compromise safety in the area being protected.

Maintenance procedures should be undertaken only by personnel trained in the operation, maintenance and repair of flammable gas detection apparatus.

If the maintenance facility is not adequately equipped and/or qualified personnel are not available to perform the manufacturer's recommended checkout and maintenance procedures, the user should return the apparatus to the manufacturer or other qualified outlet for repair.

Complete, explicit instructions for testing and checkout of replaceable apparatus components may be obtained from the manufacturer. Suitable parts lists are provided in the instruction manual.

After any defective operations are corrected (repaired or replaced in strict accordance with the manufacturer's instructions), a full workshop calibration test, as described in 11.8, should be conducted.

11.3.2 Fixed apparatus

Repair or maintenance of fixed apparatus (whether incorporating single-point sensors, open-path sensors, a combination of these, or sampling systems) should be carried out under a controlled procedure. Defective apparatus should be removed for repair in a workshop outside the area being protected. If a replacement apparatus cannot be provided immediately, then transportable apparatus should be used as a temporary substitute.

11.3.3 Portable and transportable gas detection apparatus

For portable and transportable gas detection apparatus, it is important that the whole unit should be removed to a non-hazardous location for repair and testing.

11.3.4 Off-site maintenance, general

Defective units should be

- a) returned to the manufacturer;
- b) returned to a repair agent authorized by the manufacturer;
- c) repaired in a special workshop set up by the user for gas detector maintenance, or
- d) permanently taken out of service.

11.3.5 Maintenance procedures

11.3.5.1 General

Given the variety of apparatus available, it is not practical for this standard to tabulate each maintenance, repair and calibration step in detail. What follows is a listing of the principal items that all maintenance procedures should include.

11.3.5.2 Procedure

If an apparatus is in the workshop for scheduled maintenance, the full maintenance procedure should be conducted. If specific apparatus failure is the cause of return, the complaint should be noted and only applicable check-out tests need to be conducted. However, all apparatus should undergo a full calibration test before being returned to service.

11.3.5.3 Record

The apparatus maintenance record for the apparatus should be reviewed for previous service history. See Annex D for typical apparatus maintenance record for flammable gas detectors.

11.3.5.4 Failure

When receiving a failed apparatus, it should be determined if the apparatus power supply (including any voltage regulation stages and/or battery chargers supplied) is the primary cause for failure before proceeding further.

11.3.5.5 Replacement/Repair

After checking the power supply, repair personnel should proceed with the checkout of sensors, flow systems readout devices and alarm devices – identifying and correcting all deficiencies. The manufacturer's instructions should be followed when deciding whether to replace an assembly or repair it by replacing a component part. If components are replaced, the replacement components should meet the specifications and tolerances of the original components.

11.4 Sensors

11.4.1 General

Depending on the time interval since the last sensor replacement, anticipated field usage, and response to the gas mixture during calibration, good maintenance practice suggests sensor evaluation/replacement at service intervals recommended by the manufacturer. It is further recommended that sensors be evaluated after exposure to high concentrations of flammable gas or after severe impact or mechanical vibration has occurred.

11.4.2 Flame arrestor

If a flame arrestor is part of the sensor assembly, it should be checked for proper attachment and fit, and signs of corrosion, dirt or moisture. Any necessary cleaning or replacement should be in accordance with the manufacturer's instructions.

11.5 Flow systems

This subclause is applicable only to apparatus utilizing aspirated sampling.

11.5.1 General

The flow system shall be checked for leakage, restrictions, and proper aspirator bulb or electrical pump operation. Any necessary cleaning, repair or replacement should be in accordance with the manufacturer's instructions. A cause for leakage can be cracked or otherwise damaged pump diaphragms or piston rings as appropriate to the pump type.

11.5.2 Filters, traps and flame arrestors

All filters, traps and flame-arresting assemblies should be emptied, cleaned or replaced in accordance with the manufacturer's instructions.

11.5.3 Flow system and sample chamber

The flow system and sample chamber should be examined for deposits of foreign material and steps taken to prevent future occurrences.

11.5.4 Flow connections

All flow connections should be tightened in accordance with the manufacturer's instructions.

11.5.5 Moving parts

All valves and moving pump parts should be lubricated *only* according to the manufacturer's instructions.

NOTE Silicone compounds typically should not be used for this purpose; check with the manufacturer if there is any question regarding the acceptability of silicone compounds or other materials.

11.5.6 Automatic sample-draw systems

Automatic sample-draw systems should be adjusted to correct flow rate values using recommended test apparatus.

11.5.7 Trouble signals

The loss-of-flow trouble signals should be checked for proper operation.

11.6 Readout devices

11.6.1 General

If the apparatus incorporates a meter, perform the following procedures:

- a) inspect the meter for broken or cracked lens;
- b) inspect analogue meters for defects – for example bent pointers, loose dials, loose up-scale and down-scale stops, etc.;
- c) inspect digital meters for defects – for example missing segments, faded segments, etc.;
- d) conduct other electrical and mechanical meter tests which the apparatus manufacturer deems necessary to assure proper performance.

11.6.2 Other readouts

Other readouts (for example solid state) and outputs (for example alarm outputs) as may be incorporated should be tested (electrically) at specified test points according to the manufacturer's instructions.

11.7 Alarms

If alarms are incorporated, check for proper alarm operation by offsetting electrical zero (or by other methods as recommended by the manufacturer) until the alarm(s) is(are) initiated. Check failure (malfunction) circuits by disconnecting components (or other actions recommended by the manufacturer) and observing whether or not the failure alarm operates.

11.8 Workshop calibration test and equipment

11.8.1 Calibration kits and test equipment

All calibration mixtures and associated calibration apparatus should have appropriate characteristics to ensure reliable results. The essential components of calibration apparatus are as follows:

- a) A calibration gas mixture is required, under pressure in a cylinder. This is normally, intended to give a specific response usually somewhere between 25 % and 90 % of full scale on the gas detector. Typically this is certified or analysed to be accurate to at least ± 5 % of the actual labelled concentration. The cylinder may be specially treated internally if the calibration gas is intended to simultaneously calibrate a flammable gas sensor and a sensor for a toxic reactive gas.
- b) In some cases, an apparatus calibrated for a flammable vapour cannot readily be provided with stable calibration mixtures in the form of compressed cylinders or low-pressure containers. In these cases, the manufacturer should provide relative response data to permit the use of more commonly available gas mixtures for calibration.

- c) A suitable regulator assembly is required to reduce compressed cylinder pressure. Depending on the gas detector to be calibrated this can have outputs of a pre-set or adjustable low pressure. However in many cases the calibration gas has to be supplied without pressurisation to the sensor, so the regulator and other equipment may be necessary is required to permit adjustment of flow rate to the apparatus manufacturer's specified value.
- d) For aspirated apparatus, traditional methods, providing gas at atmospheric pressure to simulate normal sampling, use bladders inflated with calibration gases. Alternatively the regulator is chosen to provide a higher flow than the aspirator will draw and there will be a blow-off tube to atmosphere for the surplus flow. More recent equipment has a demand regulator incorporated in the pressure regulator c) above, so that it delivers gas as required if a slight negative pressure is applied to its output.
- e) For diffusion apparatus and some aspirated apparatus, the regulator in c) above is configured as a flow regulator, either pre-set with or without flow indication, or adjustable and equipped with a flowmeter.
- f) For connection to aspirated apparatus a tube is usually all that is required. However special calibration adapters are required for diffusion types of apparatus. These are designed by the gas detector manufacturer to ensure that the calibration gas mixture surrounds the sensor(s) and keeps ambient air out. But more importantly, by the combination of their design and a designated controlled flowrate, they are designed to produce the same response on a test gas as would be obtained using the same gas in their normal diffusion mode.
- g) This calibration system should be resistant to absorption of, and corrosion by, the calibration mixture. This can necessitate the use of special materials, particularly where sensors for reactive toxic gases, such as H_2S or Cl_2 , are incorporated with flammable gas detectors.
- h) Some modern portable gas detectors with internal microprocessors and data links have dedicated gas calibration apparatus with data links capable of producing test reports on an associated computer, running vendor-supplied software. This may also produce specified readings based on relative response data so that an apparatus calibrated on a methane-air mixture will nominally read correctly for example on pentane.
- j) In other cases, particularly fixed apparatus, there is a hand-held controller with a data link capable of communicating with the apparatus and making the adjustments.
- k) In many of these last two cases, there is a program that requires a very specific calibration gas mixture applied in a particular way, particularly flowrate.

In view of all of these variables, when determining the gas and equipment necessary to calibrate such sophisticated gas detectors the first, and perhaps only, choice must be the equipment recommended by the vendor for that particular model of gas detector.

11.8.2 Conduct of workshop calibration testing

11.8.2.1 General

The calibration equipment or kit should be chosen as in 11.8.1 of this standard.

11.8.2.2 Gas mixture

All tests should be conducted in a manner to ensure safe venting of calibration mixtures.

11.8.2.3 Stabilization

Apparatus should be allowed to stabilize at operating temperature, and then operating controls should be adjusted in accordance with the instruction manual.

11.8.2.4 Zero check

It is usual to conduct a zero check using fresh air, or, where the air cannot be guaranteed to be uncontaminated, using zeroing gas (usually dry air) from a cylinder, and the rest of the calibration equipment as in 11.8.1.

11.8.2.5 Span calibration

The calibration system should be connected to the apparatus and the final span reading noted. The calibration should be adjusted, if necessary, so the output reading equals the concentration of the calibration mixture, or a predetermined readings. In some cases, this may be performed completely automatically. The calibration mixture should be removed, and it should be ascertained that the apparatus returns to "zero." This procedure may require repeating if the apparatus zero and span adjustment interact.

11.8.2.6 Alarm verification

Ascertain that any/all alarms are actuated when the set point(s) is reached. The manufacturer's recommendations should be followed when selecting the calibration mixture for apparatus with alarms, as the concentration required is usually slightly higher than the nominal alarm setting (to guarantee prompt alarm actuation).

11.8.2.7 Maintenance record

The calibration test herein described shall be the last conducted before an apparatus is released from the workshop. It is recommended that the calibration data be recorded on the instrument maintenance record. The instrument maintenance record (or comparable document) should be updated before returning the apparatus to service. See Annex D for a typical instrument maintenance record for flammable gas detectors.

Annex A (normative)

Measuring principles

The measuring principles of various types of sensors are given below in more detail than Clause 5 for the main benefit of engineers and managers for selection, design and installation as well as trainers. This annex provides the advantages, common applications and limitations for nine generic types of gas analysers. The limitations include interference and substances causing loss of sensitivity (poisons).

By their very nature, catalytic sensors in Clause A.1 and the flame temperature analyser (FTA) in Clause A.7 directly detect flammable gases by burning and therefore can not detect non-flammable gases and vapours. The other types of sensors described later in this section indirectly infer the presence of flammable and other gases by the response of the sensor to other gas properties.

For the convenience of the reader, Table A.1 is a copy of Table 1 in Clause 5 with references changed to suit this annex.

Table A.1 – Overview of gas detection apparatus with different measuring principles

	Catalytic sensor	Thermal conductivity sensor	Infrared sensor	Semi-conductor sensor	Electro-chemical sensor	Flame ionisation detector	Flame temperature analyser	Photo ionisation detector	Para-magnetic oxygen detector
Details in clause	A.1	A.2	A.3	A.4	A.5	A.6	A.7	A.8	A.9
O ₂ required in gas sample	Yes	No	No	(No)	(No)	(No)	Yes	No	Not applicable
Typical measuring ranges Combustible gases	≤ LFL	(0)-100 %	0-(100) %	≤ LFL	≤ LFL	≤ LFL	< LFL	< LFL	Not applicable
Typical measuring ranges for oxygen	Not applicable	Not applicable	0-(100) %	Not applicable	0-25 % (0-100 %)	Not applicable	Not applicable	Not applicable	0-100 %
Combustible gases not measurable	Large molecules	See A.2	H ₂	(See A.4)	Alkanes	H ₂ ; CO	(See A.7)	H ₂ ; CO; CH ₄ IP>X ⁵	Combustible gases
Relative response time ¹	Depends on substance	Medium	(Low)	Depends on substance	Medium	Low	Low	Low	Low to medium
Interference of non-combustible gases ²	No	CO ₂ ; Freons	(Yes)	SO ₂ ; NO _x H ₂ O	SO ₂ ; NO _x	ClHCs ³ ; Halon	(Halon)	Substance IP < X ⁵	NO; NO ₂
Poisoning ²	Si; (Hal ⁴); (H ₂ S); Pb	No	No	Si; Hal ⁴ ; SO ₂	(No)	(Si)	No	No	No
External gases required	No	No	No	No	No	Yes	Yes	No	(Yes/No)

Table A.1 (continued)

NOTE 1	Qualitative comparison between principles. The values do not take into account time for aspirated sampling lines.
NOTE 2	Table gives common examples.
NOTE 3	Chlorinated hydrocarbons.
NOTE 4	Organic halogenated or inorganic halogen compounds.
NOTE 5	IP is the ionisation potential of the substance; X is the detector UV-lamp energy.
(No),(Yes)	For information on the statements in brackets, refer to the corresponding clause.

A.1 Catalytic sensors

The principle of operation of catalytic sensors depends upon the oxidation of flammable gas on the surface of an electrically heated catalyst typically operating at a temperature between 450 °C and 550 °C. The catalyst is usually in the form of a filament of catalytic material, or as a porous ceramic bead, impregnated with catalytic material, surrounding a heater filament.

This oxidation causes a measurable temperature increase of the sensing element approximately proportional to the concentration of flammable gas detected. The sensing circuit is normally constructed as an electrical half-bridge with two electrically similar filaments or beads mounted close to one another, one is active and the other is inactive. This second, usually non-catalytic element acts as a reference, so that effects of pressure, temperature and humidity may be compensated out and have no significant effect within the specified range.

The resultant change of electrical resistance in the active sensor is then electrically converted to the output signal, usually by unbalancing a Wheatstone, or similar, bridge arrangement.

The fact that an oxidation reaction occurs means that both the flammable sample and oxygen are consumed by the process and have to be continually replaced, and the products of combustion have to leave, either by a diffusion process or in an aspirated sample stream.

A sufficient concentration of oxygen in the surrounding atmosphere, in the order of 10 % or greater, is required for catalytic sensors to operate. Since oxygen is required, detection apparatus should use this type of sensor only for gas concentrations up to the lower flammable limit in normal atmospheres.

Catalytic sensors are susceptible to permanent or temporary inhibition of the catalyst by certain contaminants such that the sensor may eventually produce low, or zero response to the presence of gas. Permanent inhibition, usually known as 'catalyst poisoning', may result from exposure to substances such as silicones, tetraethyl lead, sulphur compounds and organo-phosphorus compounds, which either produce a layer of solid products of combustion on the catalytic surfaces, or otherwise modify the surfaces. In some cases temporary inhibition may be caused by, for example, some halogenated hydrocarbons.

So-called "poison resistant" sensors tolerate much higher doses of those contaminants before they suffer inhibition.

Catalytic sensors, particularly the bead types, are capable of continuous operation for a few years in the absence of major poisoning, but will progressively drift and lose sensitivity due to ageing and traces of poisons. For this reason regular response checks and recalibration is required, the frequency depending on the severity of the application.

Sensor enclosures in most cases incorporate a permeable metal device to allow gas to reach the sensing element and to ensure that if the gas is above LFL and is therefore ignited by the hot sensing elements, this does not ignite the atmosphere outside the enclosure. This protection is also useful against dust or mechanical damage, as well as protection against air currents.

A catalytic sensor may be used in either

- a) diffusion mode; or
- b) aspirating (electrically or hand-pumped) mode.

A.1.1 Common applications

Catalytic sensors are suitable for:

- the detection in principle of all flammable gases, but with variations in sensitivity;
- the detection of gas/air mixtures up to the lower flammable limit (LFL).

The response time and sensitivity depend on the individual gas to be measured. The larger the molecular mass and molecular size of the gas, the longer will be the response time, and generally, the lower will be the sensitivity.

A.1.2 Limitations

The catalytic sensor depends upon catalytic oxidation for its principle of operation and it functions only when sufficient oxygen is present. Insufficient oxygen concentration may occur at high flammable gas concentrations well above the LFL. Therefore, this type of sensor can only be used for the detection of gas/air mixtures up to the lower flammable limit.

WARNING – With concentrations above the lower flammable limit, a catalytic sensor may erroneously indicate that the concentration of flammable gas is below the LFL.

Therefore, apparatus fully complying with IEC 60079-29-1, or the former IEC 61779 series, using catalytic sensors must have a locking overrange indication to prevent erroneous readouts due to this limitation. However, stand-alone sensors (e.g. 4-20mA transmitters) and older apparatus may not provide such protective features.

The effect of air speed on diffusion systems is commonly reduced by the mechanical construction of the detector and by use of a permeable sintered metal element.

Changes of pressure, temperature and humidity have no significant effect within the specified range. However the lower the alarm level is set the greater will be the significance of variations in temperature and other environmental factors.

To prevent false alarms, it is recommended that the alarm level should not be set below 5 % LFL for methane, 10 % LFL for propane and butane and 20 % LFL for gasoline vapours, provided suitable precautions are taken against toxicity in the last case.

After exposure to concentrations of gas in excess of the measuring range, or for prolonged periods, the sensor may need a recovery time of several hours or may have irreversible changes to its zero gas reading and sensitivity.

For reasons given in the last three paragraphs, the sensors are not suitable for high sensitivity applications (e.g. ranges much less than 0 – 10 % of LFL), as amplification would merely amplify these undesirable features.

A.1.3 Interferences

The measuring principle is generally not selective because all flammable gases (in air) induce a signal. There is a wide variation in sensitivity to different gases which is not directly correlated to the LFL. However, it is possible to use the verified relative sensitivity (as supplied by the manufacturer) for the gas to calibrate the apparatus.

If the atmosphere to be monitored contains gas or gases that dilute or displace air, for example nitrogen or carbon dioxide, the catalytic sensor may give a low or even zero response. Similar problems may occur in steam-laden atmospheres, quite often owing to saturation of the sintered flame arrestor due to condensation. High concentrations of inert gas (for example argon or helium) may also change the thermal balance of the sensor resulting in apparent reading of combustible gas.

A.1.4 Poisoning

Catalytic sensors are susceptible to poisoning by substances many of which are not obviously present but are fairly widely used, necessitating regular response checking and recalibration.

This inhibition may be permanent or temporary according to the nature of the contaminant.

Permanent inhibition, usually known as "catalyst poisoning", may result from exposure to such substances as:

- silicones (e.g. waterproofing, adhesives, release agents, special oils and greases, certain medical products);
- tetraethyl lead (e.g. leaded petrol, particularly aviation petrol 'Avgas');
- sulphur compounds (e.g. sulphur dioxide, hydrogen sulphide);
- halogenated compounds (e.g. some halogenated hydrocarbons);
- organo-phosphorus compounds (e.g. herbicides, insecticides, and phosphate esters in fireproof hydraulic fluids).

In some cases, halogenated hydrocarbons and sulphur compounds may only cause temporary inhibition.

So-called "poison resistant" sensors can tolerate higher doses of these contaminants than traditional sensors before they suffer inhibition. In achieving this their other properties may suffer (e.g. they may have a lower speed of response and reduced sensitivity).

Those that are not "poison resistant", in some cases, may be protected against most poisons by the use of activated carbon or other types of filter. However, filters should be used with great care because, while they may offer excellent protection from contaminants, carbon filters in particular will cause a reduced sensitivity to, and may even prevent the detection of, higher hydrocarbons. They also may result in considerably extended response times for substances other than methane or hydrogen, effectively limiting their application to these gases. Filters have a limited lifetime and require replacement. Their performance may also be affected by the level of humidity in the atmosphere.

An alternative technique sometimes used to reduce the effects of poisoning is the electrical operation of the sensor in an intermittent mode. This technique may also be used to reduce battery consumption. However, there are circumstances in which such sensors may give a false response, for example when they are suddenly exposed to a high concentration of gas during the "power-off" part of the switching cycle. Particular caution is necessary when using such portable apparatus in leak-detection mode or in similar operations.

The effect of poisoning depends on the poison itself, the gas to be measured and the particular design of the sensor. The manufacturer's guidance should be sought regarding which contaminants may poison the catalyst and how the sensor may be protected.

A.2 Thermal conductivity sensors

The principle of operation of the thermal conductivity sensor depends upon the heat loss by conduction (and sometimes convection as well) of an electrically heated resistance element (i.e., filament, bead or thin film resistor) located in a gas sample stream of constant flowrate, or in a diffusion chamber.

A considerably lower temperature is required for this type of sensor than for catalytic types. Consequently sensor life is essentially indefinite in the absence of corrosion or contamination.

The sample is not consumed or altered by the sensor, and it does not require oxygen. Therefore, the reading may even be taken with a stopped flow.

The temperature of the element, which determines its electrical resistance, is determined by the loss of heat through the surrounding gas and is dependent on the molecular mass and other physical properties of the molecule. When there is a change of gas composition the filament temperature changes and the resulting change of electrical resistance is then determined in a similar manner to catalytic sensors (see Clause A.1). Usually, there is a compensation element in a reference gas stream, or sealed reference gas, to eliminate the influence of external temperature fluctuations.

This type of sensor is suitable for monitoring those gases whose thermal conductivity in the desired detection range differs greatly from that of the reference environment (usually air). However, published tables of thermal conductivity may be misleading as other effects like convection or mass transport also influence the sensitivity of the sensor.

This limits the technique to relatively high concentrations, usually above the lower flammable limit. Apparatus incorporating thermal conductivity sensors should not be used for measuring gas concentrations below the LFL except in the case of gases such as hydrogen for which such sensors are especially sensitive.

The response to a gas mixture is indeterminate unless the proportions of all the constituent gases in the mixture are known, including gases not required to be detected. In the worst case, a mixture of high and low thermal conductivity gases, for instance caused by a variation in the background gas from the intended background, could cancel out the response of the gas of interest.

A.2.1 Common applications

These sensors do not require oxygen for their operation and are capable of measuring concentrations up to 100 % v/v gas.

The apparatus may be calibrated in any suitable range up to 100 % of a nominated gas in a nominated background gas.

These sensors are suitable for detecting individual gases of high or low conductivity, relative to air, where air is the reference environment. Typically the high conductivity gases hydrogen, helium and neon have a good sensitivity in air, and the sensitivity for methane is usually acceptable.

The sensitivity is often limited and the minimum practical detection limit may exceed the LFL unless the thermal conductivity of the gas is sufficiently different from that of air.

A special application is for the purging of LPG tanks with CO₂/N₂ 'inerting' gas. When thermal conductivity is combined with convection it is possible to produce sensors which are largely independent of a range of background gases (e.g. air, nitrogen and certain carbon dioxide / nitrogen 'inerting' gases). At the same time these will respond with at least comparable sensitivities to a range of lower hydrocarbons from methane to pentane, although thermal conductivity data alone would indicate that this is not possible.

A.2.2 Limitations

The technique is limited to applications where anticipated variations to the background gas have a negligible effect when compared to the response(s) of the gas or gases of interest in the required range.

The sensors are not selective for individual gases. They will respond to all gases whether flammable or not;

The thermal conductivities of flammable gases differ widely. Lighter gases (e.g. methane and hydrogen) are more conductive than air whereas heavier gases (e.g. non-methane hydrocarbons) are less conductive. The response to a gas mixture is therefore indeterminate unless the proportions of all the constituent gases in the mixture are known. In the worst case, a mixture of high and low conductivity gases could cancel each other out and produce no apparatus response.

Errors may also result if

- a) a flow-sensitive type of thermal conductivity sensor is used and the gas sample flow is not stable, or if the recommended conditions of gas flow are not maintained as per the manufacturer's instructions;
- b) there are variations in ambient temperature without compensatory ambient temperature control on the complete sensor;
- c) the apparatus is used in an unintended orientation, particularly if it is a type employing convection as well as conductivity.

A.2.3 Interferences

Interference or errors will be caused if the apparatus is exposed to, or is used to attempt to detect, gases for which it is not calibrated. Specifically additional or unanticipated gases whether flammable or not, of different thermal conductivities to the background can affect the resulting conductivity in either direction, so that the signal may even be reduced to zero.

A specific interference in many cases is water vapour since it can be highly variable, particularly in hot climates. In the higher sensitivity applications the signal due to likely water vapour variations may be sufficient for the apparatus to require sample conditioning.

A.2.4 Poisoning

There are no known poisoning effects.

A.3 Infrared sensors

The principle of operation of optical sensors depend upon the absorption of energy of a beam of light, in the ultra violet, visible, or infrared parts of the spectrum, by the molecules of the gas being detected. Most existing apparatus operate within the infrared (IR) spectrum.

Most gases absorb infrared energy. The exceptions are monatomic gases (e.g. helium, neon and argon) and symmetrical diatomic gases (e.g. hydrogen and nitrogen). Oxygen is unusual in that it has a weak absorption at a wavelength not normally used for detection of any other gas.

All other gases will absorb infrared energy, to a greater or lesser extent, at their own bands of wavelengths which are characteristic for the types of chemical bonds in them. Selecting appropriate bands for detection in an apparatus provides a means of achieving selectivity

This measuring principle is therefore of great use in monitoring most other gases in air, since the three major components of dry air; nitrogen, oxygen and argon, have a negligible effect on both zero and upscale readings in the band of wavelengths commonly used.

Characteristic bands of wavelengths are similar for families of compounds. For instance there are bands characteristic of hydrocarbons and many other organic substances that are particularly useful for flammable gas detection, since apparatus selecting these can detect all of these compounds with varying sensitivities.

However, there are many cases where there is overlap of the absorption bands of non-flammable substances and other substances that may not be required for detection, the most common being water and carbon dioxide. If these overlapping wavelengths cannot be adequately filtered in the apparatus there will be interference from these substances.

Infrared sensors do not consume the sample, and they do not require oxygen for their operation. They are largely unaffected by flow rate. Sensor life is expected to be long in the absence of corrosion, contamination or mechanical damage.

Due to a wide range of construction methods, which can partly be combined, it is virtually impossible to summarise the optical properties for the infrared detection of combustible gases. However, their main features are as follows below.

Light from a source passes along an optical path and, after filtering, reaches an optical detector. The light source may be a (tungsten) bulb lamp or a light emitting diode (LED) usually emitting in the near infrared region. The optical chamber will typically have a short length. However, the optical chamber may be greater than 30 cm in length, in which case it will require a homogeneous flow across the full optical path for proper percentage of LFL output gas indication. It can be open (or nearly open, shielded by a diffusion barrier) or a sealed cell with gas inlet and outlet. There may also be a reference chamber.

Light filtering is performed either by periodically bringing filters into the optical path or using static filters sharing parts of the path. Filters can be solid optical high pass low pass or band pass material. They can also be sealed cells with optical windows containing high concentrations of those gases expected in the sample and most likely to interfere with the gas of interest, which will remove the interfering wavebands.

Frequently, the light beam is chopped to operate the detector with a modulated signal. The reference wavelength(s) are located in regions, where unattenuated transmission is expected. Detectors may be photo-diodes, photo-multipliers, photo-resistors, vacuum photocells, semiconductor cells, opto-acoustical detectors, opto-thermal-capacitative systems (usually with negative filtering), pyroelectric detectors, etc. Fibre optics may be inserted at the ends of the optical path to prevent the sensitive optical parts from damage or corrosion and to facilitate protection against ignition by optical or electrical components of the apparatus.

Detection apparatus with infrared sensors may take various forms but may be categorized as:

- a) specifically adapted analysers with sampling systems;
- b) single-point, self-contained infrared detection apparatus suitable for installation in potentially explosive atmospheres; these may have closed cells with internal pumps or diffusion screens or have fixed length open paths to the atmosphere.
- c) light "pipes" – for example a fibre optic cable which directs an infrared light source from a control unit to a sensor cell at a remote location.

The principle of this type of apparatus allows the use of self-diagnostics to verify the response to the gas. Other advantages include

- a) high stability capability;
- b) no ambiguity at concentrations above the LFL;
- c) immunity to poisoning effects;
- d) reduced maintenance through self diagnostics. Automatic calibration, checking capabilities for malfunctions of the infrared source, and compensation for dirt accumulation on the optics, may extend operation periods between service. However, special consideration should be given to clogging of protective filters in the gas path since this will not normally be detected by self diagnostics.

NOTE Open-path, infrared radiation detection apparatus, operating on a line of sight across a space, differs from the other types mentioned in this standard in that it does not measure the concentration of gas at a particular point location, but rather measures the path integral of gas concentration along an investigative beam. It is therefore capable of detecting the presence of gas over a wider area than other types. However, it is inherently not capable of distinguishing between a high concentration of gas occupying a short section of the open path, and a low concentration of gas occupying a longer section of the path, and therefore does not comply with IEC 60079-29-1.

A.3.1 Common applications

Infrared sensors are calibrated to detect a particular gas or, in some cases, a range of gases. Other gases will not be detected if their infrared absorption band is outside that of the calibration bandwidth. Apparatus incorporating such sensors should therefore be used only for the detection of gas mixtures for which they have been calibrated.

Infrared detectors can not respond to hydrogen. However they may be used for the detection of most other flammable gases, in any specified range of concentration from a few hundred parts per million up to 100 % v/v gas. The longer the optical path is made, the higher will be the sensitivity.

By appropriate selection of both wavelength and optical path length it is possible to have apparatus for:

- measuring the total amount of hydrocarbons, often using the waveband associated with the range of C-H vibrational transition (about 3,3 μm).;
- selective measurement of one single component (in a mixture);

- measurement down to parts per million levels;
- measurement up to 100 % v/v of flammable gas;
- measurement up to 100 % v/v of oxygen.

Measuring range and performance should be selected according to each application.

A.3.2 Limitations

These sensors will not detect hydrogen.

The time taken for the gas concentration in the optical path to reach the same value as the atmosphere to be measured will limit the response time of the apparatus. This can be fast particularly in aspirated apparatus. However, in practice, weather protection housings, gas filters and hydrophobic barriers, where fitted, will limit the response times attainable.

Pressure variations do not affect the zero gas reading, but sensitivity is normally proportional to partial pressure. Since the sensor is sensitive to pressure, care should be taken to prevent alteration to the gas outlet pressure of the apparatus, see instruction manual.

Some types of sensor relying on intermittent infrared beams or photoacoustic principles are susceptible to vibration.

Some types of infrared sensors, particularly open-path designs, are sensitive to misalignment caused by shock and vibration.

Temperature effects are usually small but may increase or decrease the signal.

A.3.3 Interferences

Other components (combustible or non combustible) may induce a signal. Serious errors are likely to occur with some detectors due to interfering gases such as carbon dioxide.

Variations of water vapour concentration in the background gas can cause interference with many applications, including general-purpose infrared flammable gas detectors. However, apparatus for this purpose that complies with the requirements of IEC 60079-29-1 will have minimal interference with water.

Solid and liquid contaminants will also absorb infrared energy, causing interference or loss of sensitivity. It is important to prevent contamination of the optical components (e.g. windows and mirrors) by particulate matter or condensation. When particulate filters are used to keep optical components clean, they may become blocked under excessively dirty conditions.

A.3.4 Poisoning

There are no known poisoning effects.

A.4 Semi-conductor sensors

The principle of operation of the semi-conductor sensor depends upon changes of electrical conductance that occur by chemisorption on the surface of the heated sensing element when exposed to gas other than air. Gas concentrations are inferred by measuring the change of resistance.

The semiconducting material is usually metal oxide, often based on tin oxide. It is electrically heated up to a few hundred degrees Celsius. Electrodes are implanted or otherwise mounted on the surface.

Sensors are used for the detection of gases in any concentration, however, they tend to have a non linear response as sensitivity decreases with increasing concentration. In many cases, semiconductor sensors require oxygen to operate, and humidity or oxygen changes may effect their response.

Some semiconductors also respond to substances other than flammable gases and vapours, they are in general non-specific and susceptible to interference. There are large differences in response factors for combustible gases. Hydrogen is detected at high sensitivity, whereas some gases (e.g. NO₂) may produce negative signals, so the influence of interference gases has to be investigated for every individual application.

Consequently this type of sensor is normally used for the low cost detection of a specified gas in a nominated range of concentrations and under specific conditions.

Response times depend on the manufacturing properties of the sensing element, the concentration of the gas to be measured, and the gas transport system to the sensor (mostly by diffusion but aspiration may be used).

A.4.1 Common applications

Semi-conductor sensors may be used for the detection of gases over a wide range of concentrations, including very low concentrations, however, they have a non-linear response.

They are suitable for leak detection, even at very low concentrations, and for alarm-only apparatus.

A.4.2 Limitations

Semi-conductor sensors for flammable gases are generally non-specific, vulnerable to both humidity changes and interfering gases and may exhibit drift both of zero and span. Some gases, for example NO₂, produce negative signals.

NOTE Normally, the manufacturer will give guidance on substances that will inhibit operation of the sensor or produce false indications.

New sensors may need a long "burn in time" (up to weeks) for stabilisation of zero and sensitivity before calibration. This preconditioning should be carried out by the manufacturer.

Further preconditioning may be necessary after long periods (> 1 day) without power.

After exposure to concentrations of gas in excess of the measuring range, the sensor may need a recovery time of several hours or may have irreversible changes to its zero gas reading and sensitivity.

A.4.3 Interferences

The measuring principle is not selective, non combustible gases may induce a negative or a positive signal.

There is a wide variation in sensitivity between sensors of the same type to particular gases and in addition, the relative sensitivity for these gases may vary significantly from one sensor to another. In general, there is a very wide variation in sensitivity to different gases which is not directly correlated to the LFL. Refer to the instruction manual.

Variations of oxygen concentration, temperature, humidity or air speed may have a strong influence on the sensitivity. Refer to the instruction manual.

A.4.4 Poisoning

The sensitivity may be strongly affected (mostly decreased, but in some cases increased) by poison concentrations higher than those which affect catalytic sensors. Examples of such poisons are:

- basic or acidic compounds;
- silicones;
- tetraethyl lead;
- sulphur compounds;
- cyanides;
- halogenated compounds.

The manufacturer's guidance should be sought regarding which poisons affect the sensitivity of the sensor and how the sensor may be protected.

A.5 Electrochemical sensors

The principle of operation of electrochemical sensors depends upon the change of the electrical parameters of electrodes in contact with an electrolyte when a specific gas is present. The change in the electrical parameters occurs due to a chemical reduction / oxidation (redox) reaction of the gas of interest at the surface of an electrode.

Electrodes and electrolyte are usually confined in a cell with a semi-permeable membrane permitting gas molecules of all types to diffuse through to the electrode-electrolyte interface. In most cases a layer of a precious or semi-precious metal is deposited on the inside of this membrane and forms the electrode at which the gas molecules of interest will react. The electrodes may be covered with an activating layer, which is responsible for the reaction.

Inside the cell are at least one other electrode and the electrolyte. Variations in the electrode and electrolyte materials, whether a polarising voltage is continuously applied, and the precise way in which the electrodes are employed in the circuit, are used to obtain specificity to different gases.

Some electrochemical sensors may use an additional chemical pre-reaction, the products of which result in the electrochemical reaction at the contact surface of electrode and electrolyte.

Usually the gas of interest is consumed by the redox reaction, and the reaction products are commonly transported through the cell to the counter electrode. Since only small quantities of gas can be consumed at the electrode, diffusion may additionally be limited by aperture or capillary means to prevent the system from overloading.

The electrodes or electrolyte in electrochemical sensors may gradually be modified or consumed by reactive gases. The sensors require recalibration at suitable intervals to correct for drifts in zero and sensitivity, and ultimately require replacement. Typical lifetimes under favourable conditions can exceed 2 years.

Their response time and recovery time $t(90)$ are comparatively long (typically > 30 s), especially after overload and near the end of their life. There are usually limits on low temperature and low humidity operation.

A.5.1 Common applications

Electrochemical cells are compact, require little power, and have a high sensitivity to certain gases.

Electrochemical cells are not available for detecting most hydrocarbons (for example the alkanes, methane, ethane, propane, etc.)

However, there are a limited number of applications of this type of sensor for explosion prevention. They are suitable for measuring concentrations of hydrogen or carbon monoxide up to the LFL, and oxygen up to 25 % v/v. There are also sensors available for up to 100 % (v/v oxygen).

Additionally, these sensors are commonly used for measuring gas concentrations down to low parts per million levels, for example, in leak detection and personal monitoring for many specific toxic gases (as opposed to vapours), such as H_2S , CO, HCN, NH_3 , PH_3 , SO_2 , NO, NO_2 and ethylene oxide. Although they may be specified for a particular gas, they may detect other interfering gases.

Portable apparatus for the detection of flammable gases, using other types of sensor described in this standard for their 0-100 % LFL ranges, frequently have such electrochemical toxic gas sensors and electrochemical oxygen sensors fitted in a multi-gas configuration.

A.5.2 Limitations

Temporary, loss of sensitivity occurs in moving a cold sensor of this type into a warmer high humidity situation due to water condensing on the membrane, partially blocking it. This is particularly noticeable on oxygen sensors where a normal reading of just under 21 % can drop for this reason and give an alarm for a few minutes. Contamination by non-volatile liquids or adhesive solids can have a similar but permanent effect.

Dependent on the sensor, oxygen may be required for the electrochemical reaction. In such cases dissolved oxygen in the electrolyte will last for short periods, but prolonged operation in oxygen-free situations is not possible.

The electrolyte or one or more of the electrodes will usually limit the life of the sensor. The sensitivity will usually fall with time, requiring periodic recalibration or response checking.

Dependent on the type of sensor and the gas to be measured, the sensor may have a shortened life or a drop in response due to an overload of gas. This can happen particularly with oxygen sensors used in high oxygen concentrations, where a lead electrode is consumed proportionally to the oxygen exposure.

The lifetime of many types of sensor is also dependent on the dose of other gases because the electrolyte will be consumed. In particular, high concentrations of carbon dioxide can result in loss of sensitivity and shorten the electrolyte life in certain oxygen sensors.

In most cases the influence of temperature on the sensitivity of the sensor is well known and is reproducible. Therefore the apparatus may have electronic temperature compensation.

Low temperature or humidity may reduce the sensitivity and increase the response time of the sensor. Prolonged operation in very low humidities can dry out the electrolyte. However, some sensors have a reservoir containing material for maintaining humidity in order to avoid this effect.

Electrolyte properties will limit the low (and in some cases the high) temperature operation, see the instruction manual. There is usually a restriction around -15°C due to potential freezing.

Response time and recovery time $t(90)$ are comparatively long, typically ≥ 30 s.

A.5.3 Interferences

Electrochemical cells may respond to other gases with a positive or negative change in signal.

With the exception of oxygen sensors, the sensitivity to interference may be in some cases higher than to the gas to be measured, refer to the instruction manual.

For some types of electrochemical sensors the sensitivity is proportional to atmospheric pressure. Other types of sensor are affected or damaged by pressure pulses, refer to the instruction manual.

There are specific interference effects for oxygen sensors arising from their use in non-air gas mixtures or in the presence of very high concentrations of combustible gases, such as:

- the molecular mass of the gas in which the oxygen is measured may have a strong influence on the sensitivity of the sensor. Therefore, calibration should be carried out using a defined concentration of oxygen in the same gas;
- the lifetime of the sensor may be reduced by high concentrations of organic solvents which react with the electrolyte.

A.5.4 Poisoning

The electrolyte or the electrode may be affected by other gases resulting in a loss of sensitivity, see the instruction manual.

Apart from contamination as discussed above, the gas inlet of the sensor or membrane may be gradually reduced or even blocked by reaction products, for example, from hydrolysis of halogenated compounds like boron trifluoride (BF_3), silicone tetrachloride (SiCl_4) etc.

As mentioned, some oxygen sensors may lose their sensitivity due to high concentrations of CO_2 in the atmosphere reacting with their electrolyte.

A.6 Flame ionization detectors (FID)

The operating principle of the flame ionization detector depends upon the ionization (electrical charging) of organic compounds as they are burnt in a detector with an internal hydrogen flame. The ion cloud so formed migrates under a potential gradient of up to a few hundred volts maintained between electrodes in the combustion chamber. This results in a very low electric current, proportional to the concentration of gas/vapour in the gas stream, which is then amplified.

This type of detector has excellent linearity over a range up to several decades, from low (parts per million) concentrations up to the lower flammable limit. A flame of pure hydrogen (and air) produces a negligible number of detectable ions, giving a base current of less than 0,1 pA. This allows the measurement of mass flows of organic compounds down to 10 pg/s to 15 pg/s.

One electrode is usually the miniature flame jet itself and is negative. The positive electrode is usually cylindrical or annular, located close to and surrounding the flame.

A source of ignition (spark gap or glow plug) has to be provided in the detector.

The hydrogen flow is usually controlled at only a few tens of millilitres per minute. It should not contain organic compounds and other pollutants, but can contain some amount of gases such as nitrogen, oxygen, water vapour, etc. In most cases the sample is controlled at a flow of a few millilitres per minute, its background gas does not have to be air, and it is mixed with the hydrogen just before the flame jet.

Air for the combustion, usually at a flowrate of 100 ml/min or more, is normally fed through a ring slit into the combustion chamber. If the sample is mixed with the hydrogen as above, this air should be free of organic contaminants. Otherwise, for simpler portable or transportable devices, intended for detecting low concentrations of organic gases in air, this can be a flow of the air sample itself, eliminating the need for a separate air supply.

All gas flows should be held constant at optimised levels and the temperature of the combustion chamber should be stabilised.

The response time of an FID is mainly determined by time to feed the sample gas to the flame; response times below one second can be obtained.

The ionisation process in the flame depends on the type of atoms and their oxidation state. As an empirical rule, C-H bonds, unsaturated C-C bonds and C-halogen bonds are ionised and measurable. In hydrocarbons the response is roughly proportional to total carbon.

So the relative responses of different hydrocarbons expressed in mole fractions are roughly proportional to the number of carbon atoms in their molecules. However for oxygenated compounds, this relative response gets modified: C-O bonds in molecules do not produce detectable ions. The apparent number of carbon atoms needed to calculate the signal has to be reduced by half for each oxygen atom in the molecule. For instance formic acid HCOOH does not give a response (1 carbon minus $\frac{1}{2}$ for each oxygen equals zero). This effect reduces the empirical response if the FID is used as total carbon analyser.

However, there are major deviations from the empirical rule for response factors in the range of 1:3 to >3:1, compared to methane. Response factors also depend on the construction of the combustion cell, gas flow and electrical parameters, whether the sample is added to the hydrogen or is used as the combustion gas, and the choice of carrier gas.

Inert and rare gases, nitrogen oxides, halogens, nitrogen, oxygen, carbon dioxide, carbon tetrachloride, and water give no response.

Care should be taken if silicon-containing molecules are present in the sample gas, because an isolating layer of silica may coat the electrode, which may inhibit the ion transport or cause trouble with insulation, and thus reduce the detector signal.

A.6.1 Common applications

This type of sensor is used where high sensitivity, wide measuring range, small measuring uncertainty, poison resistance and fast response time are of main interest. The sensor is suitable for measuring ranges from the parts per million level up to the LFL and even above.

Almost all organic compounds, most of that are flammable, will give a signal. The notable exceptions are formaldehyde and formic acid which do not give a response.

This type of sensor is suitable for the measurement of gas at elevated temperatures.

A.6.2 Limitations

The principle of operation is not selective because generally all organic compounds cause a signal. If different gases are expected at the place of operation, the sensor should be calibrated for that gas to which the apparatus is least sensitive. Within limits, however, relative responses are more calculable than other techniques

Apart from the few organic exceptions already mentioned, these sensors are also not suitable for the flammable inorganic gases; hydrogen, carbon monoxide, ammonia, carbon disulphide, hydrogen sulphide and hydrogen cyanide.

The sensors will also detect some organic compounds that are not flammable.

External gases, hydrogen and (usually) synthetic air for its combustion are required. However in some cases the sample itself may be used as the combustion air. The signal is critically dependent on both sample and hydrogen flow rates, and less so on the combustion air flow. Therefore pressure of the gas sample, air and flammable gas should be kept constant, but it should be noted that the flame arrestors used in the sampling line can be soiled and difficulty may be experienced in keeping the sample flow constant.

A.6.3 Interferences

Halogenated hydrocarbons reduce the response when the apparatus is calibrated for measuring the total carbon content of the gas mixture.

The sensor cannot be used with high concentrations of gases that will extinguish the flame for example halons.

A.6.4 Poisoning

Generally there is no poisoning effect, but if silicones or other substances that result in solid combustion products are present, they may result in a coating of the electrodes and insulation which will reduce the sensitivity and ultimately make the sensor inoperative.

A.7 Flame temperature analysers (FTA)

The operating principle of the flame temperature analyser detector depends upon the rise in temperature of a flame burning a constant flow of hydrogen (or some other gas) by flammable contaminants in the air sample supporting the flame's combustion.

Inside a small detector chamber the temperature of the flame is measured by a detector. The resulting signal is non-linear in relation to the gas concentration detected.

The response time of an FTA is mainly determined by time to feed the sample gas to the flame; response times below 5 s can be obtained.

The burner gas (usually hydrogen) should be of constant composition. To ensure a stable zero signal, in the absence of the gas to be measured in the combustion air, all gas flows should be held constant at optimised levels in order to maintain a stable temperature of the combustion chamber.

Care should be taken in the presence of halon in the gas to be measured. Gas samples containing halon but not containing combustible gas will reduce the flame temperature; this should be detectable by the apparatus. Halon at high concentrations in the presence of combustible substances may cause a misreading and may even extinguish the flame.

A.7.1 Common applications

This type of sensor is used to measure the total amount of flammable gases and vapours below the LFL when a fast response time is required.

This sensor is suitable for the measurement of gas at elevated temperatures.

A.7.2 Limitations

It is non-specific as the response depends only on the calorific nature of the sample. At higher concentrations the response is not linear. For range limitations refer to the instruction manual.

The analyser is not recommended for measurement in parts per million ranges.

External gas(es) are required. Hydrogen or another fuel is required for the flame. Either oxygen is required in the gas to be measured, or a separate air supply needs to be provided for the burner. The signal is critically dependent on the flow rates of sample, fuel, and, where used, combustion air. Therefore, as in FID, pressure of the gas sample, air and flammable gas should be kept constant, but it should be noted that the flame arrestors used in the sampling line can be soiled and difficulty may be experienced in keeping the sample flow constant.

A.7.3 Interferences

Halogenated hydrocarbons, such as halons at high concentrations may decrease the signal by reduction of the flame temperature

A.7.4 Poisoning

There is no known poisoning effect.

A.8 Photo ionisation detector (PID)

This detection principle is based on ionisation of gases by ultraviolet (uv) radiation from a special lamp of known wavelength, and hence photon energy, usually quoted in electron-volts eV (e.g. 10,6 eV). This lamp is at one side of a detector cell. Gas molecules present in the cell with a lower ionisation potential (IP) than the lamp's output will become ionised by the radiation, and a current will then flow between two electrodes in the cell which have an electric potential applied between them. This current is proportional to the concentration of the substance over several orders of magnitude.

The main components of a PID are the uv-lamp with lamp driver (high voltage or high frequency method), two collector electrodes with amplifier, and typically a sample filter and pump. No consumable gases are required.

Substances with higher IP values than the lamp will not be detected. For instance, substances like ethane, propane, acetylene or methanol have IP's higher than the 10,6 eV value of the most common lamp. Other substances with values just below, such as ethanol and ethylene with a IP of 1,5 eV give a low response.

In principle, as the measurements are usually performed in air, all substances having an IP higher than oxygen (IP = 12,1 eV), such as hydrogen, carbon monoxide and methane, cannot be detected. There is no point in having a lamp of higher value than this.

The technique is not specific to flammable gases, and with the more common ultra violet lamps, it will not detect all flammable gases.

Ionisation potential of various substances can be found in the literature or a list may be obtained from the apparatus supplier. Examples of compounds which can usually be detected include: organic molecules containing several carbon atoms and/or heteroatoms such as oxygen, sulphur, bromine; non-saturated and aromatic hydrocarbons; amines; several inorganic combustible compounds such as ammonia, hydrogen sulphide and carbon disulphide; and some non-combustible gases such as nitrogen dioxide, nitric oxide and trichloroethylene.

Relative responses are generally well known so that is possible to pre-program them into software. After recalibration on a standard gas, if the identity of the gas to be detected is inputted, a direct readout can therefore be obtained.

The response time is determined by the sample gas flow only. Typical response times are between 2 s and 10 s.

A.8.1 Common applications

This type of sensor is used where high sensitivity, poison resistance and fast response time are the main requirements.

Although the technique is suitable for fixed operation, the apparatus may be portable (hand held) or transportable type and usually will have an aspiration pump built in. In this form the technique is suitable as spot reading apparatus.

This sensor is suitable for the measurement of gas concentrations from low parts per million range up to approximately 2 000 parts per million. Thus it is suitable for measurements from toxic levels to low percentages of LFL.

Additionally, this type of sensor is commonly used for measuring gas concentrations down to low parts per million levels for short periods of time, for example, in leak detection.

A.8.2 Limitations

The measuring principle is not selective for combustible gases. It will detect all substances which have an ionisation potential (IP) lower than the energy of the UV-lamp.

The sensor can not detect carbon monoxide, hydrogen, or methane in air.

The sensor will not detect compounds having ionisation potentials higher than the lamp energy of the detector. Most sensors have a UV lamp with an energy of 10,6 eV.

Thus it is unsuitable for low alkanes and some other substances, however, lamp energies may range from 8,4 eV (which will eliminate many other substances) to 11,7 eV for use in air, which will permit more gases to be detected, (refer to the documentation of the apparatus).

The higher energy lamps tend to have reduced lifetimes.

This type of sensor is not recommended for measuring higher concentrations than about 2000 parts per million because the response is not linear. For range limitations refer to the instruction manual.

A.8.3 Interferences

The sensor will respond to all substances having an ionisation potential (IP) lower than the energy of the UV lamp, typically 10,6 eV, but the response factor depends strongly on the ionization properties of the gas.

Humidity may induce a signal equivalent to several ppm. This signal is not related to ionisation (IP of H₂O is 12,6 eV) but may be caused by an interaction with material surrounding the electrodes.

A high concentration of methane in the presence of the substance to be detected may reduce the reading by inhibiting the ionisation.

Condensed material, solid material, fingerprints, etc. on the lamp or cell windows can alter the ultraviolet intensity and hence the sensitivity.

A.8.4 Poisoning

Generally there is no known poisoning effect.

The measurement of certain compounds like esters or styrene may lead to decomposition products being deposited on the UV lamp. Therefore regular cleaning of the UV lamp is recommended (refer to instruction manual).

A.9 Paramagnetic oxygen detector

Oxygen is strongly paramagnetic (attracted to a magnetic field). Nitric oxide is about half as paramagnetic. Nitrogen Dioxide is about 4 % as paramagnetic as oxygen. Other gases are two orders of magnitude less paramagnetic or very weakly diamagnetic (repelled by a magnetic field). Gases containing oxygen will tend to be drawn into a strong magnetic field with a force proportional to the oxygen fraction. NO and NO₂ will be drawn to a proportionately lesser extent and other gases have a negligible effect, making the technique effectively highly specific for oxygen in the absence of appreciable amounts of nitric oxide.

There are various techniques used to exploit this effect. Apparatus of the dumb-bell type utilises a very light, small, diamagnetic dumb-bell with a torsion suspension mounted in a strong non-uniform magnetic field. Torsion of the dumb-bell, caused by the attraction of paramagnetic gas into the magnetic field and trying to displace the dumb-bell, is detected optically and a feedback loop electromechanically returns the dumb-bell back to balance. The feedback current required is therefore proportional to the concentration of paramagnetic gas. The signal requires compensation for pressure and temperature. The apparatus is also sensitive to shock and vibration, but can be made transportable.

Apparatus of the thermo-magnetic type uses the temperature dependence of the paramagnetic susceptibility which is approximately inversely proportional to temperature. The gas flow is divided into two paths. Gas in one stream is heated to approximately 100 K above ambient. A flow ('magnetic wind') is induced in the non-uniform magnetic field because of the difference in susceptibility of the paramagnetic gas at the two temperatures. This flow is detected by its cooling effect on a heater mounted in a bridge circuit. The out-of-balance signal from the bridge is used to measure the concentration. The apparatus reading will usually be orientation dependent, therefore the apparatus should be fixed.

Apparatus based on the differential pressure (Quinke) effect transduce the pressure difference induced by flow of a paramagnetic gas attracted by a non-uniform magnetic field. A reference gas such as nitrogen with a very low flow rate is required. Pressure measurements, where the signal is proportional to gas concentration, are usually performed by modulating the magnetic field.

A.9.1 Common applications

This type of sensor is used for measurement of oxygen where selectivity, long term stability, and poison resistance are the main requirements.

This sensor is suitable for the measurement of oxygen concentrations in ranges between 0 % to 1 % v/v and 0 % to 25 % v/v oxygen. Measurement of up to 100 % v/v is possible. The difference between the lower and upper limits of the measuring range has to be greater than 0,5 % v/v oxygen.

Dependent on the particular detection method used, response times between 6 s and 40 s are typical.

A.9.2 Limitations

Dependent on the particular detection method used, the apparatus may:

- require external gas(es);
- contain ignition sources (heater);
- be sensitive to shock and/or vibration.

In most cases pressure and/or temperature correction is necessary.

A.9.3 Interference

Except for NO and NO₂, which give signals of around 50 % and 4 % respectively of the oxygen signal at equivalent concentrations, there are no significant interference by other gases.

A.9.4 Poisoning

There is no known poisoning effect.

Annex B (informative)

Environmental parameters

The following table lists the minimum level criteria for environmental conditions within IEC 60079-29-1. For further details on test conditions and acceptance criteria, consult the referenced standard.

In all cases, the environmental conditions of the area(s) of use should be compared with the data specified by the manufacturer's instruction manual. In any case where the environmental conditions may exceed the values below or those in the instruction manual, the manufacturer should be consulted.

Table B.1 – Environmental parameters

Parameter	Based on IEC 60079-29-1
Unpowered storage	24 h at each temperature sequentially: –25 °C +20 °C (ambient) +60 °C +20 °C (ambient)
Temperature	<div>Portable/Transportable –10 °C to +40 °C</div> <div>Remote sensor –25 °C to +55 °C</div> <div>Separate control unit +5 °C to +55 °C</div> <div>Fixed with integral sensor –10 °C to +55 °C</div>
Pressure	80 kPa to 120 kPa
Relative Humidity	20 % r.h. to 90 % r.h.
Air speed	Up to 6 m/s
Vibration	All units which include a sensor: 10 Hz to 30 Hz, 1,0 mm total excursion; 31 Hz to 150 Hz, 2 g acceleration peak Control unit used with remote sensor(s): 10 Hz to 30 Hz, 1,0 mm total excursion; 31 Hz to 100 Hz, 2 g acceleration peak
Drop test	<div>Portable: fall height 1,0 m</div> <div>Transportable (< 5 kg): fall height 0,3 m</div> <div>Transportable (≥ 5 kg): fall height 0,1 m</div>

Annex C (informative)

Typical environmental and application check-list for flammable gas detectors

1. Briefly describe the application in which flammable gases are to be detected (address: sampling methods, special environments, locations)

2. If monitored points are separate from the control unit, what distances are involved?

3. List flammable gas(es) and/or vapour(s) to be detected and their approximate sample composition.

Gas or vapour component*	Concentration <u>(units)</u>	Special considerations
<hr/>	<hr/>	<hr/>
<hr/>	<hr/>	<hr/>
<hr/>	<hr/>	<hr/>
<hr/>	<hr/>	<hr/>

* List also chemical name if possible.

If more than one flammable gas is anticipated, indicate whether these gases or vapours will be present separately or in combination.

4. Is detection to be in normal (21 % O₂), oxygen-deficient, or oxygen-enriched atmospheres?

Estimated oxygen range of atmosphere to be sampled:

5. Required instrument measuring range(s) other than LFL (lower flammable limit):

6. Ambient temperature range in which the control unit is to be used:

 °C minimum to

 °C maximum

Nominal expected temperature:

 °C

7. Ambient humidity range of atmosphere to be monitored:
_____ % RH minimum to _____ % RH maximum
8. Pressure range of atmosphere to be monitored:
_____ minimum to _____ maximum
9. Velocity range of atmosphere to be monitored:
_____ minimum to _____ maximum
10. Other pertinent conditions (presence of dust, corrosives, fumes, mists, etc.). Please state type and amount, if possible.

11. Potential desensitizing agents: state whether the atmosphere may include silicone, lead, halogenated compounds, or other materials which can affect sensor performance.

12. Classification of the location in which the control unit is to be used:
Gas Group: _____ Zone: _____ Group: _____
Gas Group: _____ Zone: _____ Group: _____
13. Additional accessories required:

Annex D (informative)

Typical instrument maintenance record for flammable gas detectors

Manufacturer:

Model No.:

Date purchased:

Date placed in service:

Serial No.:

User ID No.:

Calibration gas:

Location:

Maintenance other than routine calibration

Date	Check one		Returned by	Serviced by	Nature of service and parts replaced
	Scheduled maintenance	Failure			
1					
	Comments:				
2					
	Comments:				
3					
	Comments:				
4					
	Comments:				
5					
	Comments:				

Calibration records

	Date	Comments
1		
2		
3		
4		
5		

Bibliography

IEC 60079-19, *Electrical apparatus for explosive gas atmospheres – Part 19: Repair and overhaul for apparatus used in explosive atmospheres (other than mines or explosives)*

NOTE Harmonized as EN 60079-19:2007 (not modified).

Annex ZA (normative)

Normative references to international publications with their corresponding European publications

The following referenced documents are indispensable for the application 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.

NOTE When an international publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

<u>Publication</u>	<u>Year</u>	<u>Title</u>	<u>EN/HD</u>	<u>Year</u>
IEC 60050-426	– ¹⁾	International Electrotechnical Vocabulary (IEV) - Chapter 426: Electrical apparatus for explosive atmospheres	-	-
IEC 60079-0 (mod)	– ¹⁾	Electrical apparatus for explosive gas atmospheres - Part 0: General requirements	EN 60079-0	2006 ²⁾
IEC 60079-10	– ¹⁾	Electrical apparatus for explosive gas atmospheres - Part 10: Classification of hazardous areas	EN 60079-10	2003 ²⁾
IEC/TR 60079-20	– ¹⁾	Electrical apparatus for explosive gas atmospheres - Part 20: Data for flammable gases and vapours, relating to the use of electrical apparatus	-	-
IEC 60079-29-1 (mod)	– ¹⁾	Explosive atmospheres - Part 29-1: Gas detectors - Performance requirements of detectors for flammable gases	EN 60079-29-1	2007 ²⁾

¹⁾ Undated reference.

²⁾ Valid edition at date of issue.

BSI — British Standards Institution

BSI is the independent national body responsible for preparing British Standards. It presents the UK view on standards in Europe and at the international level. It is incorporated by Royal Charter.

Revisions

British Standards are updated by amendment or revision. Users of British Standards should make sure that they possess the latest amendments or editions.

It is the constant aim of BSI to improve the quality of our products and services. We would be grateful if anyone finding an inaccuracy or ambiguity while using this British Standard would inform the Secretary of the technical committee responsible, the identity of which can be found on the inside front cover.
Tel: +44 (0)20 8996 9000. Fax: +44 (0)20 8996 7400.

BSI offers members an individual updating service called PLUS which ensures that subscribers automatically receive the latest editions of standards.

Buying standards

Orders for all BSI, international and foreign standards publications should be addressed to Customer Services. Tel: +44 (0)20 8996 9001.
Fax: +44 (0)20 8996 7001. Email: orders@bsi-global.com. Standards are also available from the BSI website at <http://www.bsi-global.com>.

In response to orders for international standards, it is BSI policy to supply the BSI implementation of those that have been published as British Standards, unless otherwise requested.

Information on standards

BSI provides a wide range of information on national, European and international standards through its Library and its Technical Help to Exporters Service. Various BSI electronic information services are also available which give details on all its products and services. Contact the Information Centre.
Tel: +44 (0)20 8996 7111. Fax: +44 (0)20 8996 7048. Email: info@bsi-global.com.

Subscribing members of BSI are kept up to date with standards developments and receive substantial discounts on the purchase price of standards. For details of these and other benefits contact Membership Administration.
Tel: +44 (0)20 8996 7002. Fax: +44 (0)20 8996 7001.
Email: membership@bsi-global.com.

Information regarding online access to British Standards via British Standards Online can be found at <http://www.bsi-global.com/bsonline>.

Further information about BSI is available on the BSI website at <http://www.bsi-global.com>.

Copyright

Copyright subsists in all BSI publications. BSI also holds the copyright, in the UK, of the publications of the international standardization bodies. Except as permitted under the Copyright, Designs and Patents Act 1988 no extract may be reproduced, stored in a retrieval system or transmitted in any form or by any means – electronic, photocopying, recording or otherwise – without prior written permission from BSI.

This does not preclude the free use, in the course of implementing the standard, of necessary details such as symbols, and size, type or grade designations. If these details are to be used for any other purpose than implementation then the prior written permission of BSI must be obtained.

Details and advice can be obtained from the Copyright & Licensing Manager.
Tel: +44 (0)20 8996 7070. Fax: +44 (0)20 8996 7553.
Email: copyright@bsi-global.com.
