Dräger

Handbook: An Introduction to Gas-Detection Technology

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Handbook: An Introduction to Gas-Detection Technology

1st Edition

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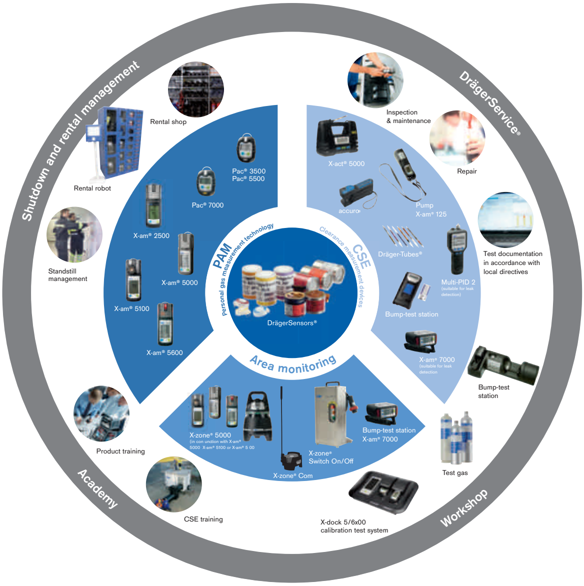
1 Gases and Vapours

1.1 Properties of hazardous gases and vapours

Flammable and toxic gases and vapours occur in many areas. It is important to recognise the danger they pose – and that is the purpose of gas-detection and warning devices. This handbook is meant to give the reader a basic introduction to gas-detection technology, measuring principles and safety concerns.



1.2 Gases – What is a gaseous matter?

Matter at a temperature above its boiling point is referred to as a gas. In terms of the human environment (normal conditions), all substances are gases whose boiling points are below 20 °C at normal pressure. The lightest gas is hydrogen (H_2, 14 times lighter than air), the heaviest gas (around ten times heavier than air) is tungsten hexafluoride (WF_6).

Under normal conditions, one cubic centimetre of gas contains 30 trillion molecules, whose average distance from one another is only around three nanometres. They move through space at between several hundred and a thousand meters per second but every second they also collide with other molecules many billions of times. The result is that they only cover around 50–100 nanometers, while constantly changing their direction and transfering energy to other molecules with which they collide.
The result is a completely random molecular motion which in macroscopic terms can be measured as temperature (average kinetic energy of all the molecules) and pressure (the average force exerted on a surface by all the molecules hitting it), as well as volume (spatial extent). Pressure, temperature and volume are always in a fixed relationship to one another that is governed by external conditions. In an ideal situation, they obey what is known as the “ideal gas law”, namely:

- **At a constant pressure, their volume changes in proportion to their temperature –** they expand, for example, when heated
- **if the volume remains the same (for example in a closed container), then their pressure changes in proportion to their temperature –** for example the pressure inside a container increases when heated
- **at a constant temperature, pressure changes inversely in proportion to volume –** for instance, the interior pressure rises when gas is compressed

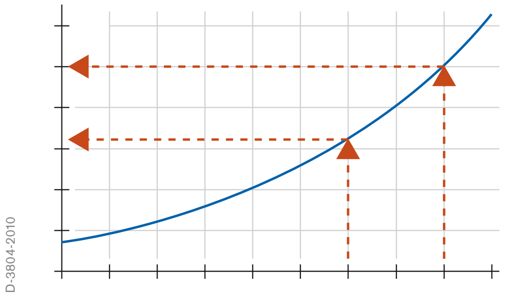
The extremely fast and random movement of gas molecules is also the reason why they mix freely with other gases, never to become separated again. This molecular behaviour also explains the tendency of molecules to become less concentrated (diffusion), something which plays an important role in gas-detection technology. Generally speaking, these processes become faster the more quickly the molecules move (the hotter the gas is) and the lower the molecular weight (the lighter the gas is).

1.3 Vapours – Aren't they gases too?

Unlike gases, of which there are perhaps only between 200 to 300, the word vapour is used to describe the gaseous state of a material below its boiling point. Vapour is always in equilibrium with its fluid (and sometimes solid) phase: it condenses and vapourises according to temperature. This is most familiar to us with water: when moist air near the ground cools down at night, ground fog forms (condensation), but the warmth of the morning sun dissipates the mist (evaporation).

In a closed container, a maximum vapour concentration always exists above the surface of a liquid. This concentration is dependent on the temperature of the liquid. On a microscopic level, the vapour is a result of the random movement of the liquid's molecules combined with their ability to overcome the surface tension and mix with the air molecules above the surface.
Every liquid has a certain characteristic vapour pressure, which is dependent only on its temperature and reaches atmospheric pressure when the liquid reaches its boiling point. A graphic depiction of this relationship is known as a vapour pressure curve and it shows the maximum possible vapour concentration at any given temperature.

Vapour pressure curve of liquid n-Hexane



If you divide the maximum possible vapour pressure by the ambient pressure, you are given the saturation concentration in Vol.-%. Hexane gas at 20 °C (vapour pressure 162 hPa) and an ambient pressure of 1000 hPa has a maximum possible concentration of 16.2 vol. %.

1.4 Our atmosphere

Our atmosphere extends – at a steadily decreasing density – far out into space. The blue colour of the sky is caused by the scattering of the sun's rays on the air molecules in the atmosphere. The sky is actually already black by the time you reach a height of around 21 km. If you were to subject the entire atmosphere to an even pressure of 1013 hPa, then it would only be 8 km high, and the UV-absorbing stratospheric ozone layer would only be a mere 3 mm high.

Typical composition of the Earth's atmosphere in ppm:

	Composition	
Gas	Dry	Humid
Main Gases		
N_2 – nitrogen	780,840	768,543
O_2 – oxygen	209,450	206,152
H_2O – water vapour	0	15,748
Ar – argon	9,340	9,193
CO_2 – carbon dioxide	340	335
Trace gases		
Ne – neon	18	18
He – helium	5	5
CH_4 – methane	1.8	1.8
Kr – krypton	1.1	1.1
H_2 – hydrogen	0.5	0.5
N_2O – nitrous oxide	0.3	0.3
CO – carbon monoxide	0.09	0.09
Xe – xenon	0.09	0.09
O_3 – ozone	0.07	0.07
Other trace gases	3.05	3.0
Total	1,000,000	1,000,000

1 vol. % = 10,000 ppm; assumption for humid air: 68 % r.h. at 20 °C

The Earth's atmosphere has a mass of around five quadrillion metric tons (5.235×10^{18} kg), which weighs down on the Earth's surface at 0.507×10^{15} m^2. This creates an atmospheric pressure on the earth's surface of 10,325 kg/m^2, which corresponds to our normal atmospheric pressure of 1013 hPa. Atmospheric pressure decreases with increasing altitude.

Altitude	Atmospheric pressure
-1,000 m	1,148 hPa
-500 m	1,078 hPa
0 m	1,013 hPa
500 m	952 hPa
1,000 m	900 hPa
1,500 m	840 hPa

Altitude	Atmospheric pressure
2,000 m	795 hPa
3,000 m	701 hPa
4,000 m	616 hPa
5,000 m	540 hPa
6,000 m	472 hPa
8,000 m	356 hPa

Since at lower atmospheric pressure there are fewer molecules present by volume, results produced by partial pressure-measuring sensors are always dependent on the atmospheric pressure.

While more than 78 vol. % of nitrogen in the Earth's atmosphere is inert, and despite the fact that it is available in excess, in this form it is not even available to plants as desperately needed fertiliser. By contrast, highly reactive oxygen is fundamental to our breathing, indeed to almost all life.

Just under 21 % of the atmosphere's volume is oxygen. A lack of oxygen is life-threatening – and cannot be detected by the nose.

Oxygen deficiency is generally caused by the release of an inert gas, which in turn displaces the oxygen. Since the atmosphere is composed of around one-fifth oxygen, the oxygen concentration is only reduced by around one fifth of the concentration of the inert gas. For example: if 10 % of the volume of the surrounding air is displaced by helium, then the concentration of oxygen is reduced by 2 vol. % and the concentration of nitrogen by 8 vol. %. Since liquid nitrogen (-196 °C) is frequently used in industry, its evaporation can quickly cause a dangerous oxygen deficiency.

Increased oxygen concentrations (e.g. more than 25 vol. %) cannot be perceived by humans but have severe consequences with respect to the flammability of materials and may even cause autoignition. This is why explosion protection is related exclusively to atmospheric oxygen concentration.

When does it get dangerous?

Oxygen concentration in vol. %	Oxygen partial pressure in hPA	Symptoms
Less than 17	Less than 170	Tendency for danger due to oxygen deficiency
11 to 14	110 to 140	Unnoticed decrease in physical and mental performance
8 to 11	80 to 110	Danger of sudden loss of consciousness after a certain period of exposure
6 to 8	60 to 80	Loss of consciousness within a few minutes – resuscitation possible if performed instantly
Less than 6	Less than 60	Immediate loss of consciousness

1.5 Ex-Ox-Tox ... gas hazard!

Gases and vapours are almost always dangerous. If gases to which we are accustomed and which we can breathe are not present in the surrounding atmosphere, then safe breathing is threatened. All gases are potentially dangerous in their liquid, compressed or even normal state – the decisive factor is their concentration

Principally, there are three categories of risk:

- Risk of explosion (Ex) caused by flammable gases
- Oxygen (Ox)
  Risk of suffocation through oxygen deficiency
  Risk of increased flammability due to excess oxygen
- Risk of poisoning (Tox) by toxic gases

Without equipment to assist, a person is unable to detect these risks early enough to be able to take protective measures. And aside from a few exceptions, our nose has proven to be an extremely unreliable warning instrument.
For example, hydrogen sulphide can be detected in low concentrations because it smells of rotten eggs. However, the nose can no longer perceive lethal, high concentrations of hydrogen sulphide. Many fatal accidents have occurred because people have fled into what they thought was a safe, odour-free area.

Even harmless gases such as argon, helium or nitrogen can also become dangerous if they are suddenly released, displacing the oxygen that is essential to life and thereby leading to risk of suffocation. An oxygen concentration of less than 6 vol. % is deadly. An excess of oxygen increases the risk of fire and can even cause flammable materials to self-ignite. By igniting, flammable gases and vapours can not only cause considerable damage to industrial plants and equipment, they can also threaten people's lives.

It is essential to detect Ex-Ox-Tox risks reliably so the appropriate measures can be taken to to protect human life, assets and the environment. Whether Dräger-Tubes or portable gas detectors, Dräger offers you individual solutions that meet your needs and enable you to counter gas risks professionally.

1.6 Toxic gases and vapours

The toxicity of gases and vapours used in industry is determined by laboratory trials which calculate the LC_{50} value*. The results of these and other scientific and occupational health tests are used by the German Hazardous Substances Committee (AGS) to set occupational exposure limits that are legally binding. Air threshold limits define the maximum concentration of a gas that a worker may inhale during his lifetime without suffering any adverse health effects. These limits must be ensured.

Limit**	Selected substances for which this limit applies
5,000 ppm	Carbon dioxide
1,000 ppm	Propane, butane
500 ppm	Acetone
200 ppm	Butanone (MEK)
100 ppm	Butanol
50 ppm	n-Hexane, toluene
20 ppm	Acetonitrile
10 ppm	Chlorobenzene
5 ppm	Diethylamine
1 ppm	1,1,2,2-tetrachloroethane
500 ppb	Chlorine
200 ppb	Methyl chloroformate
100 ppb	Chlorine dioxide
50 ppb	Glutaraldehyde
10 ppb	Methyl isocyanate

** 2010 limits

T+ Very toxic $LC_{50} < 0.5\ g/m^3$

Arsine, boron tricholoride, boron trifluoride, bromine, hydrogen cyanide, diborane, fluorine, hydrogen fluoride, ozone, phosgene, phosphine, sulphur tretrafluoride, hydrogen sulphide, nitrogen dioxide, nitric oxide, tungsten hexafluoride

T Toxic $LC_{50} = 0.5 \ldots 2.0\ g/m^3$

Acetonitrile, ammonia, benzene, chlorine, hydrogen chloride, cyanogen, carbon monoxide, methanol, bromomethane, sulphur dioxide, carbon disulphide, nitrogen trifluoride

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* LC_{50} (LC stands for lethal concentration) and refers to the concentration of a gas in the air that is required to kill 50 % of the test animals (usually white laboratory rats) by inhalation within a pre-determined period (usually four hours).

1.7 Flammable gases and vapours

The lower the LEL (lower explosive limit) of a flammable gas, the more dangerous it is. Similarly, the lower the flash point of a flammable vapour, the more hazardous it is. The flash point is defined by the liquid's temperature-dependent vapour pressure and its LEL*.

Vapour	LEL vol.%	LEL g/m^3	Flash point in °C	Vapour pressure at 20 °C in mbar	Ignition temperature in °C
Acetone	2.5	60.5	< -20	246	535
Acrylonitrile	2.8	61.9	-5	117	480
Benzene	1.2	39.1	-11	100	555
n-Butanol	1.4	52.5	35	7	325
n-Butyl acrylate	1.2	58.1	27	11	390
Butyl acrylate	1.2	64.1	37	5	275
Chlorobenzene	1.3	61.0	28	12	590
Cyclohexane	1.0	35.1	-18	104	260
Cyclopentane	1.4	40.9	-37	346	320
1,2-dichloroethane (DCE)	4.2	255.7	13	87	440
Diethyl ether	1.7	52.5	-45	586	175
1,4-dioxane	1.4	69.7	11	38	375
Epichlorhydrin	2.3	88.6	28	16	385
Ethanol	3.1	59.5	12	58	400
Ethyl acetate	2.0	73.4	-4	98	470
Ethyl benzene	1.0	44.3	23	10	430
n-Hexane	1.0	35.9	-22	160	230
Methanol	6.0	80.0	9	129	440
1-methoxy-2-propanol	1.8	67.6	32	13	270
Methylethylketone (MEK)	1.5	45.1	-10	105	475
Methyl methacrylate	1.7	70.9	10	40	430
n-Nonane	0.7	37.4	31	5	205
n-Octane	0.8	38.1	12	14	205
n-Pentane	1.1	42.1	-40	562	260
i-Propanol (IPA)	2.0	50.1	12	43	425
Propylene oxide	1.9	46.0	-37	588	430
Styrene	1.0	43.4	32	7	490
Tetrahydrofurane (THF)	1.5	45.1	-20	173	230
Toluene	1.1	42.2	6	29	535
Xylene (isomer mixture)	1.0	44.3	30	7	465

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* Lower explosive limit (LEL) values may vary according to region. The operator is responsible for choosing the relevant value.

Gas	LEL vol.%	LEL g/m^3	Autoignition temperature in °C
Acetylene	2.3	24.9	305
Ammonia	15.4	109.1	630
1,3-butadiene	1.4	31.6	415
i-Butane	1.5	36.3	460
n-Butane	1.4	33.9	365
n-Butene (Butylene)	1.5	28.1	360
Dimethyl ether	2.7	51.9	240
Ethene (Ethylene)	2.4	28.1	440
Ethylene oxide	2.6	47.8	435
Methane	4.4	29.3	595
Methyl chloride	7.6	159.9	625
Propane	1.7	31.2	470
Propene (Propylene)	1.8	31.6	485
Hydrogen	4.0	3.3	560

Source: List provided by the PTB (German National Metrology Institute)

Only flammable and combustible liquids have a flash point.
By definition, flammable gases do not have a flash point.

1.8 LEL and preventive explosion protection

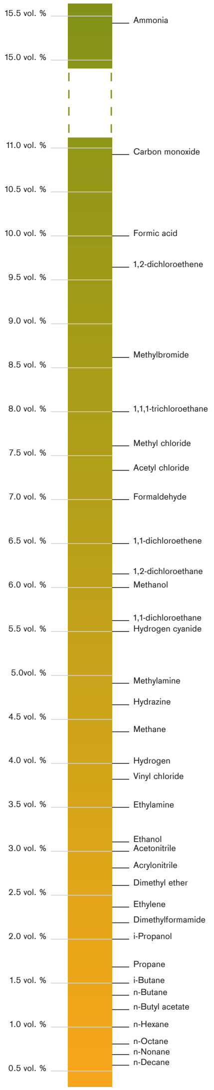
Flammable gases and vapours can form flammable mixtures when combined with air, but only if the proportion of flammable gas and oxygen (or air) is within certain limits.

The lower explosive limit (LEL) is defined as the lowest concentration of a gas in percent by volume (vol. %) in which a flammable gas and air mixture under standard conditions can be ignited and then will continue to burn independently. The LEL of all known flammable gases and vapours is in the range of approximately 0.5 to 15 vol. %. For example, the LEL of a hydrogen-air admixture is 4 vol. %. Thus, a test gas with 2 vol. % hydrogen in the air can definitely not be ignited.

Concentration limiting

This property is very important for practical explosion protection: if a flammable gas cannot be ignited below its LEL concentration, explosion protection is possible by continuously measuring the gas concentration and taking appropriate steps to ensure that, for example, half of the LEL (50% LEL) is never exceeded.

This method of preventive explosion protection is often known as the primary measure: it doesn't prevent the ignition, rather it reliably prevents a potentially explosive atmosphere from even forming. The concentration measurement are taken with infrared or catalytic bead sensors which must comply with certain technical safety requirements to be used for this purpose.

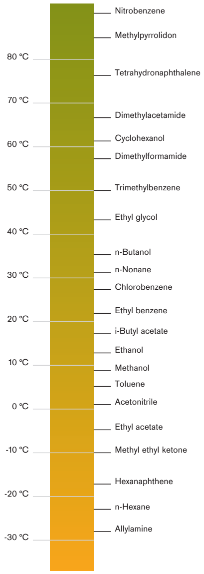


1.9 Flash point of flammable liquids

Although we speak of flammable liquids, it is not the liquid but the vapour that is flammable. Only vapour can form a flammable mixture with atmospheric oxygen. The volatility of the vapour and its corresponding lower explosive limit (LEL) is a gauge for the risk of explosion. This is indicated by the so-called flash point.

To be ignitable at all, the concentration of the vapour above the surface of the liquid must exceed the LEL. Whether it will ignite or not is determined by the amount of vapour generated. This is determined by the so-called vapour pressure, which is dependent on the temperature of the liquid. Safety regulations refer to the so-called flash point (F) when describing this explosive behaviour. The flash point is the temperature at which enough vapour is produced for the vapour-air mixture to be ignited by a standardised apparatus. If the flash point of a flammable liquid is above 50 °C, this liquid definitely cannot be ignited at a temperature of 30 °C.

The lower the flash point of a flammable liquid, the more dangerous it is. Since vapours of flammable liquids cannot be ignited below their flash points, preventive explosion protection can also be implemented by using liquids with a flash point significantly higher than the ambient temperature. This is the common practice. However, the disadvantage is that large amounts of energy are required to evaporate such liquids when they are used as solvents. By definition, gases do not have a flash point, because under normal conditions they are not found in liquid form.



You cannot ignite diesel (F > 55 °C) with a burning match, but you can ignite petrol (F < -20 °C)!

1.10 Concentrations and their calculation

Concentrations are specified as the percentage of a substance in a reference substance. For the measurement of hazardous substances in the air, the quantity of the substance is expressed as a concentration in relation to the air. An appropriate unit of measurement is chosen in order to come up with convenient figures for indicating a concentration. High concentrations are generally indicated in percent by volume (vol. %) or the number of parts of the substance in 100 parts of air. For example, air consists of 21 vol. % oxygen; therefore 100 parts of air contain 21 parts of oxygen. For small concentrations, the measurement units of parts per million (ppm or mL/m^3) or parts per billion (ppb or µL/m^3) are used. The concentration measurement ppm means one part of a substance in one million parts of air (think of a single sugar cube in a tanker). The concentration measurement ppb means one part of a substance in one billion parts of air (think of five people in the entire Earth's population). The calculation for this very small concentration in vol. % results in the simple relationship:

1 vol. % = 10,000 ppm = 10,000,000 ppb

In addition to gaseous components, air can also contain “dissolved” solids or liquid substances known as aerosols. Because these air-transported drops or particles are miniscule, a volume measurement is not used. The concentration of aerosols is measured in mg/m^3.

			vol. %	ppm	ppb
vol.%	=	10 L/m^3 1 cL/L	1	10^4	10^7
ppm	=	mL/m^3 µL/L	10^{-4}	1	10^3
ppb	=	µL/m^3 nL/L	10^{-7}	10^{-3}	1

			g/L	mg/L	mg/m^3
g/L	=	10 L/m^3 1 cL/L	1	10^3	10^6
mg/L	=	mL/m^3 µL/L	10^{-3}	1	10^3
mg/m^3	=	µL/m^3 nL/L	10^{-6}	10^{-3}	1

Calculation from mg/m^3 to ppm

$$c_{[\text{ppm}]} = \frac{\text{Molar volume}}{\text{Molar mass}}\, c \qquad c_{[\text{mg/m}^3]} = \frac{\text{Molar mass}}{\text{Molar volume}}\, c$$

The molar volume of any gas is 24.1 L/mol at 20 °C and 1.013 hPa. The molar mass of the specific gas under consideration should be used.

2 Portable Gas-Detection Technology

ST-1178-2008

2.1 Usage and requirements of gas-detection technology

In the beginning, there was the canary: these little finches would warn miners of dangerous gases underground. If they stopped singing, the miners had to go back up quickly. Such crude and inaccurate methods (of determining gas concentrations in the atmosphere) are long since history. Today, precise measuring instruments monitor the concentration of hazardous gases and flammable vapours. The latest of these are small, compact, robust and flexible single-gas and multi-gas units. Gases and vapours are not always necessarily harmful – after all, the Earth's atmosphere is made up of them. It is only when their concentration (depending on the substance) exceeds critical levels (resulting in poisoning and explosions) or conversely drops below them (resulting in a risk of suffocation through oxygen deficiency) that they can become a threat. Across the most diverse branches of industry, portable gas-detection devices are used in many different ways: scenarios range from use by individual employees and small groups of workers all the way up to large-scale operations like the industrial shutdown of an entire petrochemical plant. Instruments measuring various hazardous substances have to be reliable under changing conditions. This can also place great demands on durability and flexibility, as in the end it is detection equipment that is directly responsible for the safety and health of employees. Not every device is suitable for every working environment, so before using equipment please check that its specifications are adequate. These requirements are set out in standards and guidelines.

USAGE AND REQUIREMENTS OF GAS-DETECTION TECHNOLOGY

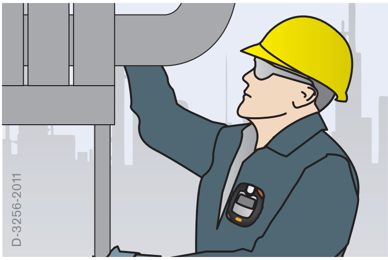
Application areas for portable gas-detection

Portable gas-detection instruments are subject to very sophisicated requirements. Highly diverse areas of application require solutions that take the respective operating conditions into account and are tailored to the specific measurement task.

It is generally possible to distinguish between the following application areas:

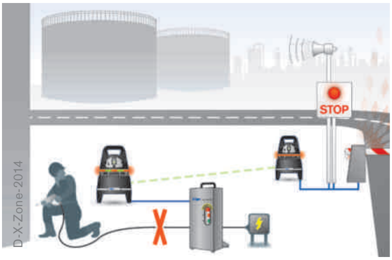
Personal monitoring

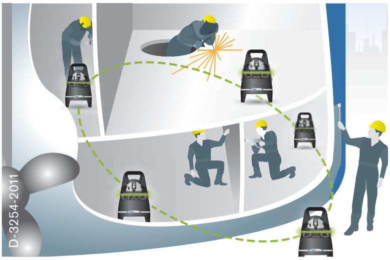
These devices are designed to warn the wearer of gas hazards in the immediate vicinity. As a result, they are usually worn directly on work clothing. The basic requirements of these units are therefore higher wearing comfort, durability and reliability. Continuously measuring single-gas and multi-gas instruments are suitable for this type of work.



Area monitoring

In contrast to personal gas-warning instruments, area monitoring devices are positioned at central or critical locations, independent of personnel, so that work areas can be monitored optimally.

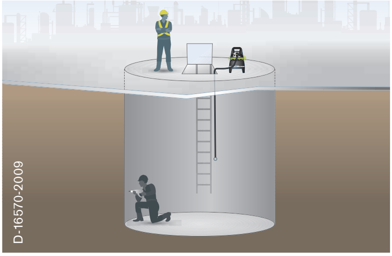




The basic requirements here are robustness, stability, well-recognised alarms (visual and audible) as well as the longest possible battery life. An increased level of safety is made possible by interconnecting area monitoring devices to form a wireless chain of alarms that transmit measurement data from device to device as well as to mobile end devices.

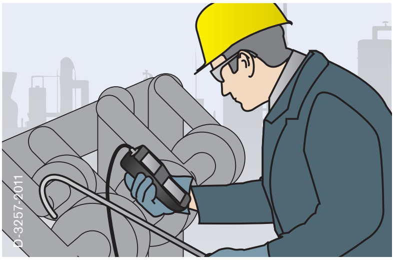
Entering confined spaces

In order to perform maintenance or repair work, it is often necessary to enter confined spaces. Limited space, a lack of ventilation and the presence or development of hazardous substances result in particularly high risks in these work areas. A clearance measurement is required before entering these environments. Multiple-gas detectors with corresponding pumps and accessories, such as hoses and probes, come into play. After successful clearance of the area, the same devices can then be used for continuous personal monitoring while working within the confined spaces.



Leak detection

Leakages can occur anywhere where gases or liquids are stored or transported. It is important to identify leaks quickly in order to take the appropriate measures to prevent people, the environment and the facility from harm. Detection instruments with corresponding pumps must have rapid response times in order to detect even slight changes in concentrations. Extreme reliability is a therefore the minimum requirement for these measuring instruments.



USAGE AND REQUIREMENTS OF GAS-DETECTION TECHNOLOGY

Requirements of gas-detection devices

As safety technology products, gas-detection instruments for industrial use must not only comply with statutory requirements (e.g. explosion protection and electromagnetic compatibility) but also fulfill additional requirements that ensure the product's quality and reliability for gas-detection even under harsh conditions.

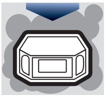
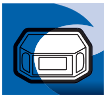
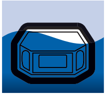
Explosion protection standards

Design requirements ensure that gas-detection devices do not act as a source of ignition. Internationally accepted standards are IEC, EN (ATEX), CSA, UL, GOST, etc.

Protection class according to EN 60529 (IP code)

The IP code provides information concerning the protective properties of the housing against foreign bodies and water.

IP = Ingress Protection Extract modelled on DIN EN 60529:

	First index number	Protection against solid foreign objects		Second index number	Protection against water
	5	Protection against contact. Protection against interior dust deposits.		5	Protection against water jet (nozzle) from any angle.
	6	Complete protection against contact. Protection against dust penetration.		6	Protection against water–penetration by temporary flooding.
				7	Protection against water–penetration by temporary immersion.
				8	Protection against water–penetration by extended immersion.

D-16533-2009

Protection class IP 67 guarantees a high degree of robustness. However, this can also have negative consequences in terms of vapour permeability. For this reason, the MEWAGG (Working Group for Detection and Warning Devices for Hazardous Gases) within BG Chemie (German Social Accident Insurance Institution for the Raw Materials and Chemical Industry) recommends that users who do not simply want to detect gases such as methane and propane but also higher hydrocarbons or solvents ask the manufacturer to confirm the suitability of the device. This could be metrological certification in accordance with ATEX, for example.

Quality of measurement functions

Compliance with predefined measurement quality, even under extreme conditions (temperature, pressure, wind, humidity, vibration, etc.)

EN 45 544	– for toxic gases and vapours
EN 50 104	– for oxygen
EN 60-079-29-1	– for flammable gases and vapours

Electromagnetic compatibility in accordance with EN 50270

Electrical or electronic devices should not interact or interfere with other devices through their electrical, magnetic or electromagnetic fields. For example, the use of a mobile phone or a two-way radio close to a gas-detection instrument should not disrupt the instrument's measurement signal and vice versa. Electromagnetic compatibility directives and standards define the means of proving and confirming a device's insensitivity to interference and low levels of emitted interference. Simply complying with the requirements of a standard or guideline may not be sufficient depending on the various local operating conditions. Rugged industrial applications require far more robust devices. Dräger pays special attention to these requirements, for example with an additional, in-house robustness test.

RoHS and REACH

The requirements for materials and substances used must also be considered during the development and production of gas-detection equipment. The European RoHS (Restriction of Hazardous Substances) directive requires that six particularly dangerous substances may not be contained in electrical and electronic devices. The REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals) regulation requires that the presence of particularly hazardous materials in products must be disclosed. Dräger seeks to avoid such substances within the scope of technical possibilites and meets the relevant directives and regulations in this regard.

USAGE AND REQUIREMENTS OF GAS-DETECTION TECHNOLOGY

Explosion protection

Industrial processes very often involve flammable substances, possibly even flammable particles. In these areas, flammable gases and vapours can sometimes be released on a process-related basis (such as relief valves) or by unforeseen incidents (breakdowns). As a means of prevention, areas such as these are designated EX areas ("zones"), in which only equipment which is reliably protected against ignition may be used.

Explosion protection is standardised worldwide; IEC (international), CENELEC (European) and NEC 505 (North American) standards are similar and based on the three-zone concept, which is also rapidly gaining acceptance in the USA.

Zone in IEC, NEC 505 and CENELEC	Dangerous explosive atmosphere exists
Zone 0	constant, regularly or long-term
Zone 1	occasionally
Zone 2	seldom and for short periods

Whereas typical American explosion protection is still based the NEC 500's two-division concept:

Division in NEC 500	Dangerous explosive
Division 1	constantly or occasionally
Division 2	seldom and for short periods

USAGE AND REQUIREMENTS OF GAS-DETECTION TECHNOLOGY

ATEX 137 – Directive 1999/92/EG

The **ATEX** directive (the acronym **ATEX** being taken from the French term **AT**mosphères **EX**plosibles, in English explosive atmospheres) has been binding on all systems since July 30, 2006 and is addressed to employers. It describes minimum requirements for the protection of employees' health and safety in areas at risk of explosion.

The directive has the following goals:
- Prevent the formation of explosive atmospheres. If this is not possible:
- Prevent the ignition of explosive atmospheres. If this is not possible:
- Reduce the harmful effects of an explosion to a tolerable minimum.

Employers are obliged to assess the risk of explosion in the relevant areas. Zone categories are defined by answering the following question: "How likely is it that an explosive atmosphere (gas, vapour, dust) will form in the areas concerned? "

ZONE DEFINITION AS PER ATEX 137, SUPPLEMENT I, 2

	Areas at risk of explosion are divided into the following zones according to the likelihood of an explosive atmosphere forming there:
Zone 0	Area in which explosive atmospheres comprising mixtures of air and flammable gases, vapours, and aerosols are present constantly, frequently or over long periods of time.
Zone 1	Area in which, under normal operation, an explosive atmosphere can occasionally form as a mixture of air and flammable gases, vapours or aerosols.
Zone 2	Area in which, under normal operation, an explosive atmosphere consisting of a mixture of air and flammable gases, vapours or aerosols normally does not form – or if so only briefly.
Zone 20	Area in which explosive atmospheres in the form of clouds of combustible dust in the air are present constantly, frequently or over long periods of time.
Zone 21	Area in which, under normal operation, an explosive atmosphere can occasionally form as clouds of combustible dust in the air.
Zone 22	Area in which, under normal operation, an explosive atmosphere in the form of a cloud of combustible dust in the air normally does not form – or if so only briefly.

Depending on the zone identification, only certain gas-measuring instruments may be used in these zones. The following table links the categories of ATEX 95 with the zones in ATEX 137:

Permitted use	Gas, vapour (G)	Dust (D)
Instruments in Category 1	Zone 0, 1, 2	Zone 20, 21, 22
Instruments in Category 2	Zone 1, 2	Zone 21, 22
Instruments in Category 3	Zone 2	Zone 22

(For device category, see section 3.5 ATEX 95)

The instrument group and temperature category requirements are then determined by defining the flammable gases, vapours, aerosols and dusts used, along with their ignition temperatures.

Extract from section 2.6 Flammable gases and vapours

Gas	LEL vol. %	LEL g/m³	Ignition temperature in °C
Acetylene	2.3	24.9	305
Ammonia	15.4	109.1	630
1.3 butadiene	1.4	31.6	415
i-Butane	1.5	36.3	460
n-Butane	1.4	33.9	365
n-Butane (butylene)	1.2	28.1	360
Dimethyl ether	2.7	51.9	240
Ethene (ethylene)	2.4	28.1	440
Ethylene oxide	2.6	47.8	435
Methane	4.4	29.3	595
Methyl chloride	7.6	159.9	625
Propane	1.7	31.2	470
Propene (propylene)	1.8	31.6	485
Hydrogen	4.0	3.3	560

Vapour in mbar	LEL vol. %	LEL g/m³	Flashpoint in °C	Vapour Pressure in °C	Temperature-Pressure in °C
i-Propanol (IPA)	2.0	50.1	12	43	425
Propylene oxide	1.9	46.0	-37	588	430
Styrene	1.0	43.4	32	7	490
Tetrahydrofurane (THF)	1.5	45.1	-20	200	230
Toluene	1.1	42.2	6	29	535
Xylene (isomer mixture)	1.0	44.3	25	7	465

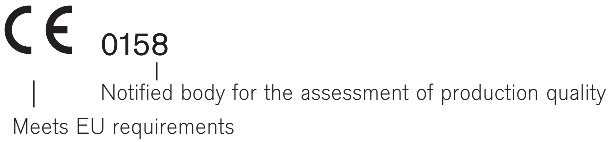
USAGE AND REQUIREMENTS OF GAS-DETECTION TECHNOLOGY

ATEX 95 – Directive 94/9/EG

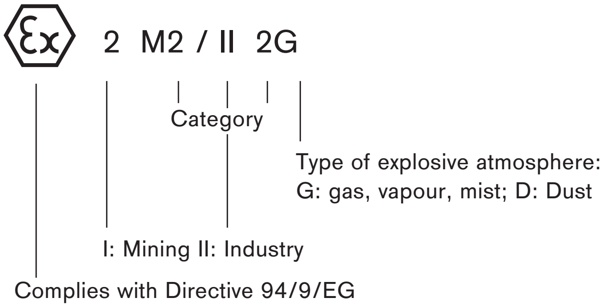
This directive applies to the manufacturers of gas-detection and warning instruments, among others. It describes the requirements that must be fulfilled by gas-detection devices used in areas at risk of explosion, and which incorporate their own potential ignition sources.

The CE symbol of conformity – coupled with information about the equipment category (describing in which zones at risk of explosion in which the gas-warning instrument may be used as an electrical device) may look like this:

Markings as defined by 94/9/EG (ATEX 95)



Marking (as defined by ATEX):



Equipment groups I and II indicate in which area the device may be used:

I = Mining

II = Industry

This is followed by information about which equipment category the gas-detection device satisfies:

Category 1	Very high level of safety, sufficient safety provided by two protective measures or in the event of two failures
Category 2	Sufficient safety in the event of frequent equipment malfunctions or one failure
Category 3	Sufficient safety if operation is fault-free

Finally, the atmosphere is indicated (G: gas, vapour, mist or D: conductive and non-conductive combustible dusts).

The designation indicates the zones in which the device may be used.

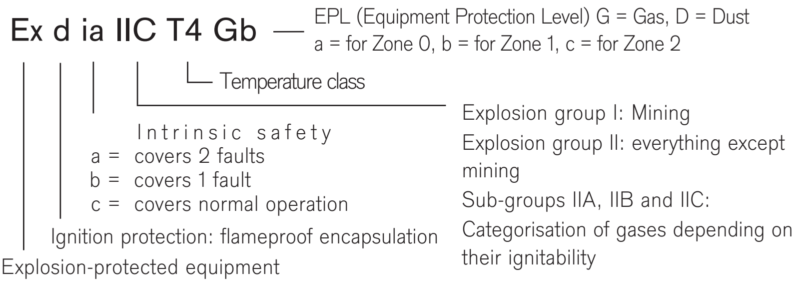
INDUSTRY

Ex area:	Zone 0	Zone 1	Zone 2	Zone 20	Zone 21	Zone 22
Ex atmosphere:	constantly, for long periods or frequently	occasionally	normally not or only for short periods	constantly, for long periods or frequently	occasionally	normally not or only for short periods
II 1G	Yes	Yes	Yes	No	No	No
II 2G	No	Yes	Yes	No	No	No
II 3G	No	No	Yes	No	No	No
II 1D	No	No	No	Yes	Yes	Yes
II 2D	No	No	No	No	Yes	Yes
II 3D	No	No	No	No	No	Yes

MINING

Device category	Safety
I M1	Very high level of safety, may remain in operation at high concentrations of methane
I M2	High level of safety, must be switched off in case of high concentrations of methane

Explosion protection symbol according to EN 60079



The requirements for electrical equipment, which are to be used in potentially explosive areas, are outlined in the standards series EN 60079. Markings are also defined. Both a marking in accordance with ATEX and a marking to indicate the equipment protection level (EPL) are required. The introduction of the EPL makes it possible to allocate the potentially explosive areas in which a device may be used, including outside of Europe.

Ignition protection types provide information about the protective measures incorporated in a device:

Abbreviation	CENELEC standard	Type of explosion protection
Gas		
	EN 60079-0	General provisions
Ex o	EN 60079-6	Oil immersion
Ex p	EN 60079-2	Pressurised enclosure
Ex m	EN 60079-18	Encapsulation
Ex q	EN 60079-5	Powder filling (sand filling)
Ex d	EN 60079-1	Flameproof (pressure-tight)
Ex e	EN 60079-7	Increased safety
Ex ia	EN 60079-11	Intrinsically safe (also for dust)
Ex ib		ia required for Zones 0 and 20
Ex ic		ib sufficient for Zones 1 and 21
		ic sufficient for Zones 2 and 22
Dust		
Ex ta	EN 60079-31	Protection by enclosure
Ex tb		ta required for Zone 0
Ex tc		tb required for Zone 1
		tc required for Zone 2

Comparison: designation according to IEC (2007) / CENELEC (2009) and EU directive 94/9/EG (ATEX)

EPL (Equipment Protection Level)		Equipment category
As per IEC / CENELEC	EU Directive 94/9/EG	Range
Ma	M1	Mining
Mb	M2	
Ga	1G	Potentially explosive gases
Gb	2G	
Gc	3G	
Da	1D	Areas with flammable dust
Db	2D	
Dc	3D	

Explosion group

Explosion group I encompasses equipment used for mining (coal dust and methane atmospheres). Explosion group II applies to all other areas (all other gases). For the ignition types “explosion/flameproof encapsulation” and “intrinsic safety”, explosion group II is subdivided into IIA, IIB and IIC. This subdivision relates to the different levels of ignitability in terms of ignition penetration and electrical sparks. Explosion group IIC covers all gases and vapours. For flammable dusts, there is also Explosion group III for flammable dusts and this in turn is subdivided in three other groups (IIIA: flammable fibres, IIIB: non-conductive dust, IIIC: conductive dust).

CLASSIFICATION OF GASES AND VAPOURS

Explosion group	Temperature class (max. permitted surface temperature)					
	T1 (450 °C)	T2 (300 °C)	T3 (200 °C)	T4 (135 °C)	T5 (100 °C)	T6 (85 °C)
Autoginition temperature	> 450 °C	300-450 °C	200-300 °C	135-300 °C	100-135 °C	85-100 °C
I	Methane					
IIA	Acetone	i-Amyl acetate	Amyl alcohol	Acetaldehyde		
Ignition energy greater than 0.18 mJ	Ammonia	n-Butane	Benzine			
	Benzene	n-Butanol	Diesel fuel			
	Ethyl acetate	1-Butene	Fuel oil			
	Methane	Propyl acetate	n-Hexane			
	Methanol	i-Propanol				
	Propane	Vinyl chloride				
	Toluene					

Explosion group	Temperature class (max. permitted surface temperature)					
Autoginition	T1 (450 °C)	T2 (300 °C)	T3 (200 °C)	T4 (135 °C)	T5 (100 °C)	T6 (85 °C)
temperature	> 450 °C	300-450 °C	200-300 °C	135-300 °C	100-135 °C	85-100 °C
IIB	Hydrogen cyanide	1,3-butadiene	Dimethyl			
Ignition energy	Town gas	1,4-dioxane	Ethyl glycol			
0.06 to 0.18 mJ		Ethylene	Hydrogen sulphide			
		Ethylene oxide				
IIC Ignition energy lower than 0.06 mJ	Hydrogen	Acetylene				Carbon disulphide

Temperature class

Group II electrical equipment is classified in temperature classes according to the maximum surface temperature of the equipment that may potentially be exposed to the hazardous atmosphere. The autoignition temperature of the gas must be higher than the maximum surface temperature. T6 includes all gases and vapours. For protection from dust explosion, the maximum surface temperature is indicated directly in °C, e.g. T130 °C.

The last part of the label, the EC type-examination certificate, provides, among other things, information about the authority that first carried out the inspection.

EC type-examination certificate

BVS 10 ATEX E 080X

X: Special conditions
U: Ex component
Certificate number
Complies with Directive 94/9/EG
Year of the EC type-examination certificate
Notified body for EC type-examination

2.2 Equipment solutions

EQUIPMENT SOLUTIONS

Choosing the measurement method

Selecting the correct measurement principle is crucial to identifying gas-related risks. Every measurement principle has its strengths and limitations and is optimised for certain groups of gases (flammable/toxic gases and oxygen).

An important question, therefore, is which gases/vapours are present where in the workplace. Generally, it is possible to distinguish between the following gas-related risks:

Risk of explosion (Ex danger)

- Wherever flammable gases or vapours exist, there is always an increased risk of explosion. This situation is typical of the following areas: mining, refining, chemical industries and many more. Infrared and catalytic bead sensors are used here. These sensors typically record the gas concentrations at the lower explosion limit (LEL) but they are also suitable to an extent for the 100 vol. % range.

Oxygen displacement / oxygen excess

- Oxygen displacement is life threatening. Oxygen excess affects the flammability of materials up to the point where they can self-ignite. Electrochemical sensors are usually used for measuring oxygen. The measurement range lies between 0 – 25 vol. % and up to 100 vol. %. Dräger-Tubes and CMS can also be used here.

Toxic gases

- Toxic substances can occur anywhere. They can be released during industrial manufacturing and treatment processes, during transport (rail, road or ship) and during incomplete combustion. Even natural processes such as biomass decomposition and decay release toxic substances.

Various measurement principles can be used to detect toxic gases.

- Dräger-Tubes
- CMS
- Electrochemical sensors
- PID sensors

Identifying the right principle for a particular application depends on several factors, such as:

- What other hazardous substances are present (cross-sensitivity)?
- Is it necessary to measure hazardous substances selectively or does it make more sense to measure a group parameter?
- Should measurement be short-term, long-term or continuous?
- Is it necessary to have warning and alarm functions when limits are exceeded?

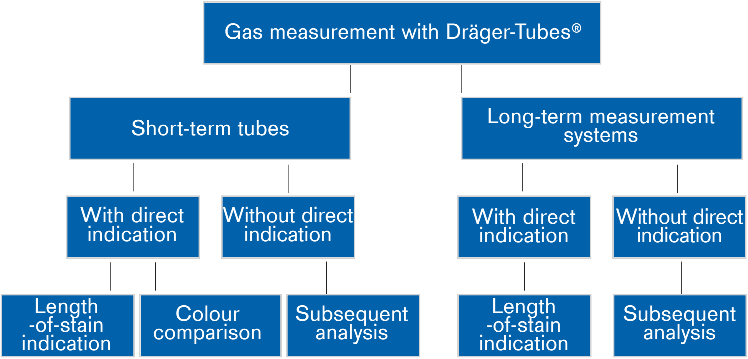
EQUIPMENT SOLUTIONS

Dräger-Tubes®

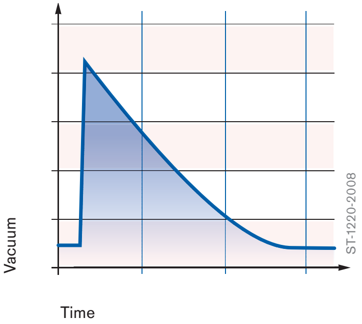
D-8774-2009

Gas-detector tubes are one of the classic measurement methods used for gas analysis today. This versatile system can be used in numerous applications in industry, fire fighting and disaster management, in the laboratory, for environmental protection and in many other areas.

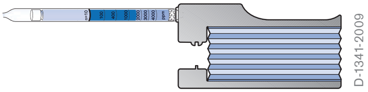
Dräger-Tubes can be schematically classified using the following criteria:



The Dräger-Tubes measurement system consists of a Dräger-Tube and a Dräger pump. Each Dräger-Tube contains a very sensitive reagent system that produces accurate readings when the technical characteristics of the gas-detector pump precisely match the reaction kinetics of the reagent system in the tube. Therefore, the volume conveyed by the pump, as well as the volume-flow schedule, the "suction characteristic", should be tailored to the tube and kept to narrow tolerances. These requirements are referenced in both international and national detector-tube standards or norms that require or recommend that detector tubes be used with a matching pump from the same manufacturer.



Suction characteristics of the Dräger pump



Dräger accuro®

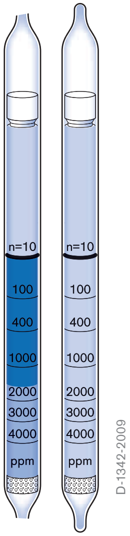
EQUIPMENT SOLUTIONS

Direct-indicating Dräger-Tubes®

Direct-indicating, short-term tubes by Dräger provide immediate and precise measurement results. Time-consuming trips to the laboratory are eliminated. Also, the tubes do not require additional calibration by the user, as the calibration is shown in the form of a scale on the tube. At present, more than 220 short-term tubes are available for the detection of up to 500 gases.

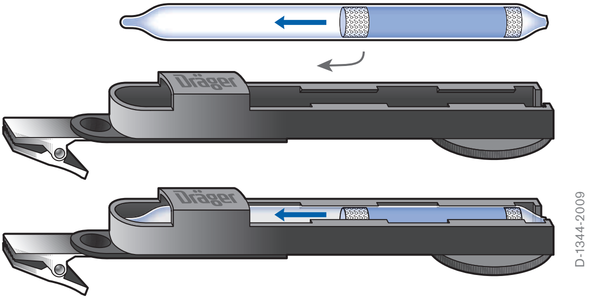
The principle is startlingly simple:

In an enclosed glass tube, the Dräger-Tube, there is a reagent system located on a solid carrier that reacts by changing colour when it comes into contact with a certain gas or vapour. A defined quantity of ambient air is drawn through the tube using, for example, the Dräger accuro pump. Even the smallest quantities of gas are sufficient to trigger a reaction. The scale on the tube allows the user to evaluate the concentration of the hazardous substance directly after the measurement. For applications in which single or less regular measurements are sufficient, Dräger-Tubes are particularly advantageous compared to electronic detection devices, as they are cheaper and easier to operate. The number of gases/vapours that can be detected is also far higher than other detection instruments with direct display.



Long-term tubes with direct indication

No pump is necessary when sampling with direct-indicating, long-term tubes. The contaminant molecules automatically move into the tube according to Fick's First Law of Diffusion. The driving force of this movement of the contaminant molecules is the concentration differential between polluted ambient air and the inside of the tube. Due to the wearing comfort of these diffusion tubes and because they do not require a pump, they are particularly suitable for personal monitoring. Diffusion tubes are used for measurements ranging from 0.5 to 8 hours. These are so-called integrated measuring devices. In other words, they add up the contaminant molecules and after approximately one shift a reading can be taken of the average.



Diffusion tube with direct indication in the holder

Further information: Dräger-Tubes® / CMS Handbook and the VOICE® database of hazardous substances at www.draeger.com.

EQUIPMENT SOLUTIONS

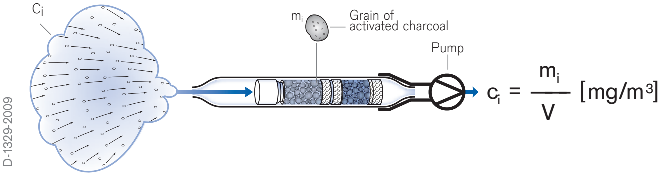
Dräger sampling tubes

A selective measurement with sampling systems and a subsequent laboratory analysis is very suitable for measuring trace concentrations (e.g. in an office or in outside air) or for complex mixtures of substances (e.g. in workplaces). The complete analysis can be forwarded to official bodies or archived for documentation purposes.

A differentiation is made between active and passive sampling

Active Sampling

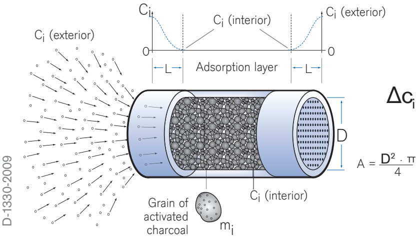
For active sampling, the air to be evaluated is drawn through a sampling tube with a pump (e.g. Dräger accuro pump). The substance to be collected from the air sample accumulates on the sorbent (e.g. charcoal). The concentration is calculated from the mass of the hazardous material, which is determined during the analysis, and the volume of the sample air.



$$c_i = \frac{m_i}{V} \; [\mathrm{mg/m^3}]$$

Passive sampling

In the case of sample collection using a diffusion sampler, the contaminant molecules from the ambient air follow a defined diffusion course and are immediately absorbed by the sorbent when they reach the absorption layer. The mass of the adsorbed hazardous substance is calculated in accordance with Fick's First Law of Diffusion. Additional detailed information: Dräger-Tubes / CMS Handbook and the VOICE® database of hazardous substances on the Internet at www.draeger.com.



$$\Delta c_i = \frac{m_i \cdot L}{D_i \cdot t \cdot A} \; [\text{mg/m}^3]$$

Dräger tube	Sample of collection type	Substance or group of substances that can be collected
Activated charcoal tubes	Active	Aliphatic, aromatic hydrocarbons, solvent vapours, ester, ketone, alcohols, glycol ether, fluorinated hydrocarbons
ORSA diffusion sampler	Passive	Aliphatic, aromatic hydrocarbons, solvent vapours, ester, ketone, alcohols, glycol ether, fluorinated hydrocarbons
Silica gel tubes	Active	Strong ionic, organic connections, such as alcohols, phenols, cresols
ADS sampling tubes	Active	Aliphatic amines and dialkyl sulfates
Aldehyde sampling set	Active	Aldehydes, such as formaldehyde, acetaldehyde, acrolein, glutaraldehyde
Isocyanate sampling set	Active	Isocyanates, such as HDI, 2.4 TDI, MDI
Nitrous oxide diffusion sampler	Passive	Nitrous oxide

EQUIPMENT SOLUTIONS

Measurement Centre & Analytical Services

Dräger Analytical Services specialises in air examinations of all areas where pollutants (hazardous substances) may be present.

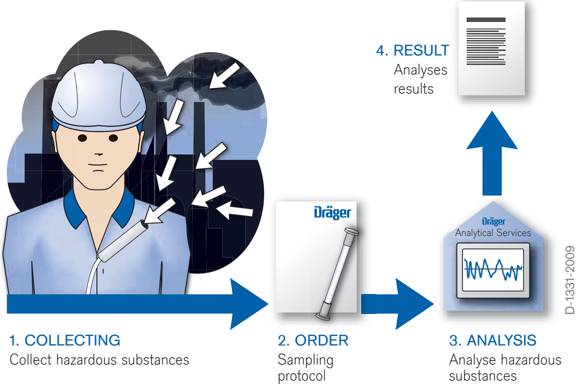
These include:

- Workplaces, where hazardous substances are dealt with;
- Offices and other interior spaces (e.g. nursery schools, apartments, assembly rooms, truck cabins, etc.) where the air may be contaminated by vapours from building materials or furnishings;
- Exhaust air from businesses and industrial plants
- Compressed air, soil vapour in contaminated soil
- Gas emissions from material samples

Independent sample collection Dräger offers suitable systems for inexpensive and independent sample collection. These consist of Dräger pumps, collection media, sample collection records and dispatch bags for Analytical Services. Recommendations for the collection of air samples and further information can be found on the Internet at www.draeger.com/Analysenservice. The collection systems used by the customer are sealed once the samples have been collected and are then sent with a sample collection record to Dräger Analytical Services in Lübeck.

Dräger Measurement Centre

The Dräger Measurement Centre, which is accredited in accordance with DIN EN ISO/IEC 17025, offers a complete range of services for managing hazardous substances. The services provided include consulting, measurement planning, execution of sample collections and measurements on-site, analysis of samples and the evaluation of results in the form of a measurement report or assessment.



Air-quality surveys at the workplace using on-site sampling followed by a laboratory analysis

EQUIPMENT SOLUTIONS

Dräger CMS chip

ST-312-98

The Dräger Chip-Measurement-System (CMS) is a new generation of chemical gas-detection technology. Dräger CMS is a system for the quantitative determination of hazardous gas or vapour concentrations in the air. Carried out primarily at worksites, the short-term measurement is used to monitor threshold values, for process control, and for measurements in canals, shafts and confined spaces. The complete measurement system consists of two main components:

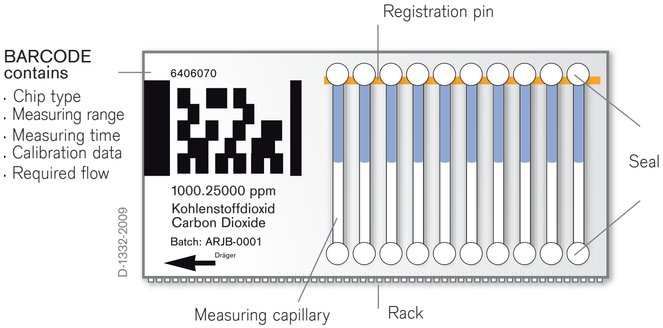
- Substance-specific chips
- Analyser for evaluating the chips

The chip

Each chip contains ten measurement capillaries filled with a substance-specific reagent system. Compared to other measurement systems, chemical reagent systems have distinct advantages. One major reason for this is the possibility to provide the reagent layer with one or more pre-layers to absorb moisture, to hold back interfering substances or to change substances into measureable substances. This ensures that the measurement result is substance-specific. The reactive preparations necessary for detection are kept in hermetically sealed glass capillaries until needed. The chip housing also protects the capillaries from possible external mechanical influences.

When the chip is inserted, the analyser automatically recognises all required information for measurement by means of a bar code:

– Substance to be measured
– Measurement range
– Measurement period
– Calibration function parameters
– Required flow rate



The chip set-up

Further information: Dräger-Tubes® / CMS Handbook and VOICE® database on hazardous substances (www.draeger.com).

EQUIPMENT SOLUTIONS

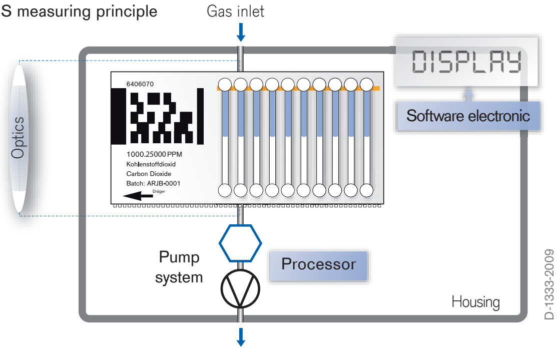
Dräger CMS analyser system

The analyser records the measurement effect optoelectronically, thereby eliminating the inadequacies of the human eye for the most part. The gas inlet for the air to be sampled is located at the front of the analyser and is protected from dust and other impurities.

When the integrated mechanics have established an air-tight connection between the entire gas conduction system and the open capillary of the chip, a special pump system pulls a constant mass-flow of air through the capillary. The pump system consists of a mass-flow controller, a processor and a small diaphragm pump. The processor regulates the pump for the necessary mass flow. In this way, fluctuations in the ambient air pressure are equalised within certain limits. No correction of the measurement result is necessary, regardless of whether the measurement is taken at the Dead Sea or in the mountain air of Mexico City.

The measurement principle of the CMS is based on a dynamic dose measurement which is dependent on concentration. The basis for this principle is chemical kinetics, whereby the speed of the chemical reaction in the capillary depends on the concentration of the sample. For the chip measurement system, this means short and defined measurement times. The measurement time is not constant but is directly related to the concentration, i.e. the higher the concentration, the shorter the measurement time. The corresponding position of the optical unit allows a direct determination of the speed of the chemical reaction within the capillary. Since concentration and reaction speed are directly proportional, the analyser terminates the measurement very quickly when high concentrations are present.

Schematic diagram of the CMS measuring principle



EQUIPMENT SOLUTIONS

Electrochemical sensors

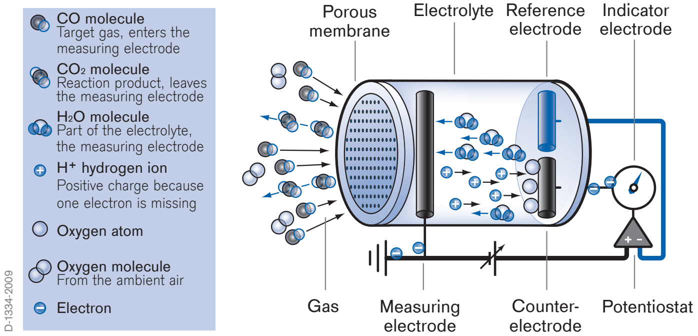
Many toxic gases are also very reactive and can change their chemical composition under certain conditions. The electrochemical sensor is a micro-reactor, which produces a very small but still measurable current in the presence of such gases. As in the case of a normal household battery, electrochemistry is involved because the chemical reaction produces electrons.

An electrochemical sensor consists of at least two electrodes (measuring electrode and counter electrode) that have contact with each other in two different ways: on the one hand via an electrical conductive medium (electrolyte: a pasty liquid as ion transporter); on the other hand via an outer electric current circuit (an electron conductor). The electrodes are made of a special material, which also has catalytic properties, enabling certain chemical reactions to take place at the “3-phase boundary”, where gas, catalyst and electrolyte are present. However, a dual-electrode sensor (measuring electrode and counter electrode) has many disadvantages. For example, should higher concentrations of gases be present, this can lead to higher currents in the sensor and a voltage drop. The voltage drop then changes the preconfigured sensor voltage. This, in turn, can lead to the production of unusable measurement signals or, in the worst case, a chemical reaction in the sensor that goes unnoticed during measurement.

For this reason, the Dräger XS and XXS sensors contain a third electrode, the “reference electrode”, which has no electrical current and whose electric potential, therefore, remains constant.

This is used to continuously measure the sensor voltage at the measurement electrode, which can be corrected by the sensor's internal control enhancement. This significantly improves measurement quality (e.g. with regard to linearity behaviour and selectivity) and leads to a longer life time.

Electrochemical sensor



Chemical reaction at the measuring electrode

$CO + H_2O \rightarrow CO_2 + 2H^+ + 2e^-$

Chemical reaction at the counter-electrode

$\frac{1}{2}O_2 + 2H^+ + 2e^- \rightarrow H_2O$

EQUIPMENT SOLUTIONS

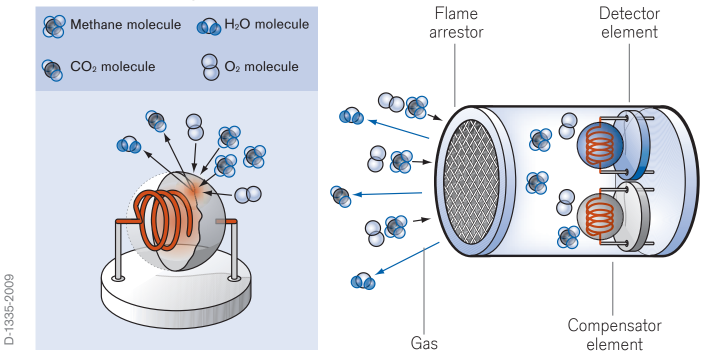
Catalytic bead sensors

Under certain circumstances, flammable gases and vapours can be oxidised by the oxygen within ambient air and release reaction heat. This is typically achieved by using suitably tempered catalyst material, which slightly increases its temperature through the resulting heat of the reaction. This slight increase in temperature is a measure of gas concentration.

A small platinum coil is embedded in a porous ceramic bead with a diameter of under 1 mm. An electric current flows through the platinum coil, heating up the pellistor to a few hundred degrees Celsius. If the pellistor contains suitable catalytic material, the pellistor's temperature will rise in the presence of flammable gas and the resistance of the platinum coil will rise accordingly. This change in resistance can be electronically analysed.

A second pellistor is used to eliminate the influence of changes in ambient air. It is very similar to the first pellistor, except that it does not react to gas (e.g. it does not contain any catalyst material or is otherwise inhibited). In this way, a sensor circuit forms in a Wheatstone bridge circuit, which is to a large extent independent of ambient temperature and can detect the presence of flammable gases and vapours in air. As the catalytic bead sensor contains hot pellistors, it can (if the LEL is exceeded) act as an ignition source. This is prevented by using a metal sinter disc. If an ignition takes place in the interior of the catalytic bead sensor, the sensor's housing withstands the explosion pressure and the flame is cooled down to below the ignition temperature of the gas. This ensures that the flame does not leave the sensor housing.

Catalytic Bead Sensors



Reaction

$CH_4 + 2\,O_2 \longrightarrow 2\,H_2O + CO_2$ + reaction heat

EQUIPMENT SOLUTIONS

Infrared sensors

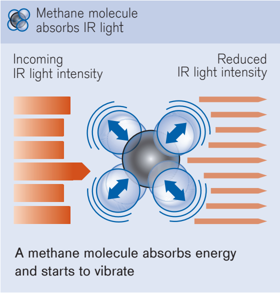
All gases absorb radiation in a characteristic manner and some do so even in the visible range (wavelength 0.4 to 0.8 micrometers). This is why chlorine is green-yellow, bromine and nitrogen dioxide are brown-red, iodine is violet and so on. However, these colours can only be seen at rather high (lethal) concentrations.

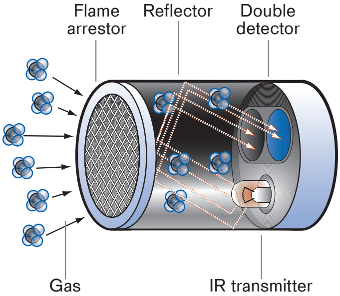
Hydrocarbons, on the other hand, absorb radiation in a certain wavelength range, approximately 3.3 to 3.5 micrometers. Since the main components of air – oxygen, nitrogen and argon – do not absorb radiation in this range, this method can be used for measurement purposes. In a closed container containing gaseous hydrocarbons (e.g. methane or propane), the intensity of incoming infrared light will be weakened. This weakening is dependent on the concentration of the gas.

Air: Infrared passes through unattenuated – the intensity remains the same
Gas (e.g. methane): Infrared light weakens when passing though – intensity is reduced according to the concentration of methane. This is the principle behind an infrared measuring instruement, as used with Dräger infrared sensors. Most flammable gases and vapours are hydrocarbons and hydrocarbons are almost always detectable because of their characteristic infrared absorption.

Functional principle: The ambient air to be measured is guided to the measuring cell by diffusion or though the use of a pump. From the infrared transmitter, wide-band radiation finds its way into the cell through a window. It is then reflected onto the mirrored walls, passing through a window onto the double detector. The double detector consists of a measurement and reference detector. If the gas mixture contains hydrocarbons then a part of the radiation is adsorbed and the measurement detector produces a small electrical signal. The signal from the respective reference detector remains unchanged. Fluctuations in the performance of the infrared source, contamination of the mirror or the window, as well as disruptions caused by dust or aerosol in the air, affect both detectors to the same degree and are therefore fully compensated.

PID Sensors



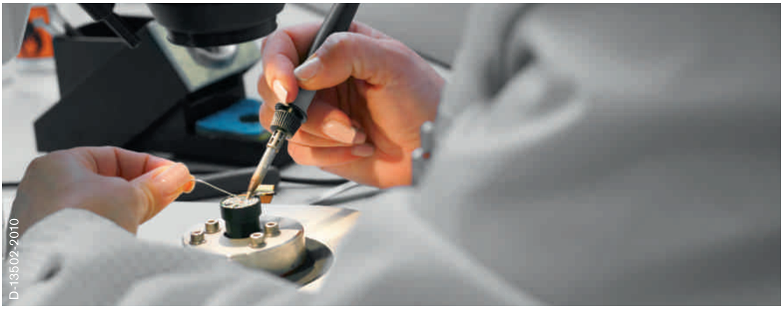


Reaction

CH_4 + Energy → CH_4 (excited)

EQUIPMENT SOLUTIONS

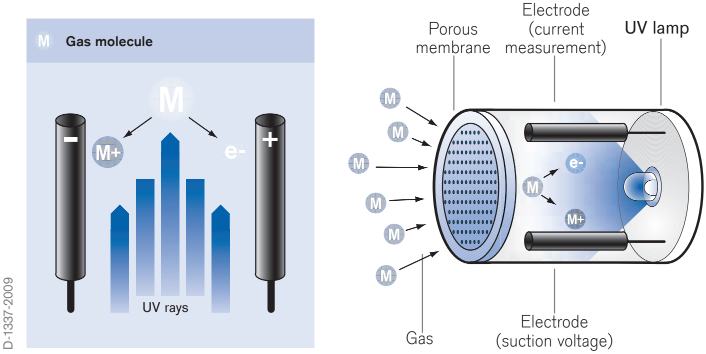
PID sensors



Many flammable gases and vapours are toxic to humans long before they reach their lower explosion limit (LEL). For this reason, an additional measurement of volatile organic substances in the ppm range through the use of a PID sensor is an ideal supplement to traditional personal monitoring.

The air is drawn in through the gas inlet into the measurement chamber. There, a UV lamp generates photons that ionise certain molecules within the gas flow.

PID Sensors



In order to ionise permanent gases in the air (such as inert gases, nitrogen, oxygen, carbon dioxide and water vapour), a relatively high amount of energy is required. For this reason, these gases do not disrupt the measurement of hazardous substances. Most organic substances which can be regarded as hazardous substances (e.g. hydrocarbons) are ionised and exposed to the electric field between the two electrodes in the measurement chamber. The strength of the resulting current is directly proportional to the concentration of ionised molecules in the detection chamber. This makes it possible to determine the concentration of the hazardous substance in the air.

Ionisation energy and UV lamps

Ionisation energy is measured in electron volts (eV) and indicates how much energy is required to ionise or charge one molecule. This ionisation energy is substance specific data, such as boiling point or pressure. In order to ionise a certain substance, the ionisation energy of that substance must be smaller than the photon energy of the lamp used with the photo ionisation detector (PID). Two different types of lamps are commonly used: the 10.6 eV lamp and the 11.7 eV lamp. A PID is suitable for detecting entire groups of hazardous substances. However, when calibrated accordingly, it can also be used to detect an individual substance.

Further information: DrägerSensor® & Portable Instruments Handbook and the hazardous substance database VOICE® at www.draeger.com

EQUIPMENT SOLUTIONS

Single-gas instruments

If the risk caused by toxic gases or vapours can be narrowed down to a single gas or one conductive component, single-gas detectors and warning instruments are the ideal solution for personal monitoring at the workplace. They are small, robust and ergonomic. The devices are typically worn directly on the worker's clothing, close to the breathing area, without restricting the worker's freedom of movement. The instruments continuously monitor the ambient air and issue an alarm (visual, audible and by vibration) when the gas concentration exceeds a preconfigured limit on the device. This allows workers to react directly to risks should incidents occur during standard operations, or if unforeseeable events occur during maintenance and repair work.

Dräger Pac 3500 – 7000

The Dräger Pac 3500 to 7000 family is equipped with XXS detectors. These are miniature electrochemical sensors that allow for a smaller, ergonomic instrument design. The sensor sits directly behind a replaceable dust and water filter, which protects it from environmental influences with negligible effects on the response times. Apart from accuracy and reliability, the response time is also plays a decisive role. The so-called t90 to t20 times provide information on how fast the sensor reacts to changes in the concentration of a gas. Due to the fast reaction time and very short diffusion paths, these sensors react extremely quickly and display any gas-related risk immediately. The sensor's electrical signal is displayed as a concentration with the help of electronics and software. Alarm thresholds are defined in the device (A1 = prewarning / A2 = main alarm). If the gas concentrations exceed these alarm thresholds, the device emits a visual, audible and vibrating alarm.

Robustness and Ex protection are two further important factors when selecting the correct gas-detection instrument.

Dräger X-am 5100

The Dräger X-am 5100 is optimised for measuring the gases / vapours hydrazine, hydrogen peroxide, HCL / HF. These special gas hazards are difficult to detect because they adsorb to different surfaces. The open gas inlet projecting from the device prevents the presence of adsorbing surfaces between the gas and the gas sensor. As a result, rapid response of the proven XS sensors is also ensured for these special gases.

DrägerSensor®
Longer operating times with Dräger XXS sensors

Large display
The clearly structured, language-free display shows all necessary information at a single glance

Stable housing
Impact resistant housing and ergonomic design

Good visibility
Coloured labels allow the instruments to be easily distinguished at a distance

D-1338-2009

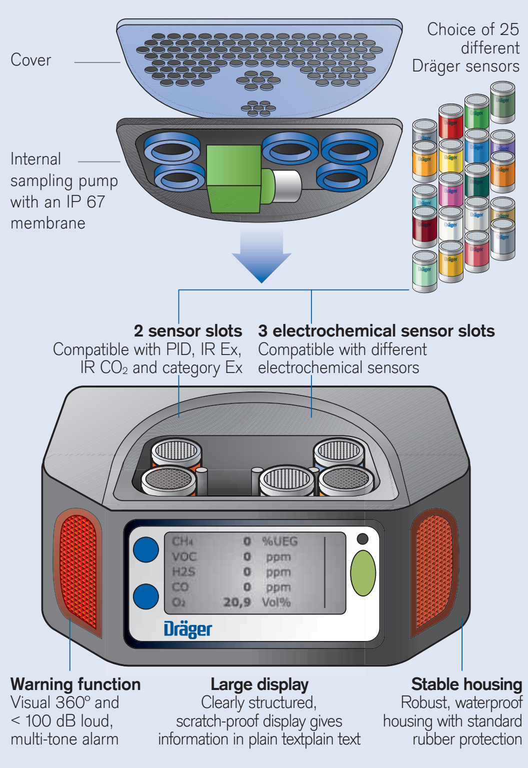
EQUIPMENT SOLUTIONS

Multi-gas instruments

If different hazardous substances (Ex-Ox-Tox) occur in the workplace, it is advisable to use continuous measurement devices for multiple gases. They offer possiblity to use different measurement principles (infrared, catalytic bead, PID and electrochemical sensors) in one device, thus taking advantage of the respective strengths of each measurement principle.

The combination of the sensors depends on the application in question. Up to six gases can be detected continuously and in real time. In addition to being used for personal or area monitoring, optional accessories also allow multi-gas instruments to be used for clearance measurements and leak detection. Multi-gas instruments include the Dräger X-am 2500, X-am 5000, X-am 5600 and X-am 7000.

Gas-measurement technology (e.g. the Dräger X-am 7000)



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EQUIPMENT SOLUTIONS

Calibration

The calibration of gas-detection devices is extremely important because, understandably, gas-detection devices cannot measure correctly until they have been calibrated correctly.

Dräger-Tube® and CMS

Both of these detection instruments are delivered pre-calibrated. Until the actual measurement, or until the expiration date, the hermetically sealed gas tube ensures that the calibration remains stable, provided that the storage conditions printed on the label are met.

Sensors / portable gas-detection instruments

Sensors are used for continuous measurements. Environmental influences or other gases can change the calibration with which the sensor is delivered to the customer. In their T 021 bulletins (Gas-Warning Equipment for Toxic Gases/Vapours) / T 023 (Gas-Warning Equipment for Explosion Protection), BG Chemie therefore recommends regular checks and calibration as necessary.

While zero calibration is rather simple because ambient air can generally be used for this purpose, calibrating sensitivity is not so straight-forward.

Precisely because electrochemical sensors often detect reactive gases, they also have to be calibrated with reactive gases – and reactive gases, even low concentrations, react with (damp) material surfaces and plastics. For this reason, it is important to keep the distances between the test gas and device as short as possible. Therefore, manufacturers of gas-detection devices provide calibration accessories that meet these requirements and are optimised for their devices.

Even though, from the safety aspect, the target gas (the gas that is to be detected) should always be used for calibration, there are several reasons for using a surrogate test gas for calibration purposes.
If the same detector is to be used to detect a variety of gases, the instrument has to be calibrated to the gas to which it is the least sensitive. This way, you are on the safe side, because the concentration of all other gases will be exaggerated. Test gases are provided as single gases and also as gas mixtures for calibrating multi-gas detectors.

EQUIPMENT SOLUTIONS

Dräger VOICE®

ST-1005-2004

The risk to humans through a variety of hazardous substances at the workplace and in the environment is increasing in our technology oriented society. But what are the right protective measures must be taken for your company and for which hazardous materials? Dräger VOICE® gives you the comprehensive information you need for your safety. Rapid, comprehensive and available at all times.

What is VOICE®?

The extensive online database, Dräger VOICE, provides you with up-to-date information on more than 1,700 hazardous substances and 11,500 synonyms. Within seconds, it produces a link between hazardous substance, measurement option and protective equipment. For further information you can resort to the user manual.
Please make sure to compare the information to the device's accompanying user manual in each individual case. The hazardous substance database is available online at www.draeger.com/voice

iOS

ANDROID

This is what you find in VOICE®:

- Comprehensive material specifications for chemical/phsical data
- German, British and American threshold values
- Risk and Safety Statements
- Data regarding the measurement of hazardous substances
- Help with finding and selecting measuring and protective equipment
- Data on personal protective equipment
- Recommendations regarding use of the collection systems
- Further information (e.g. user manuals*)

* Please compare with the user manual accompanying each delivered device.

3 Stationary Gas-Detection Technology

3.1 Usage and requirements of gas-warning instruments and systems

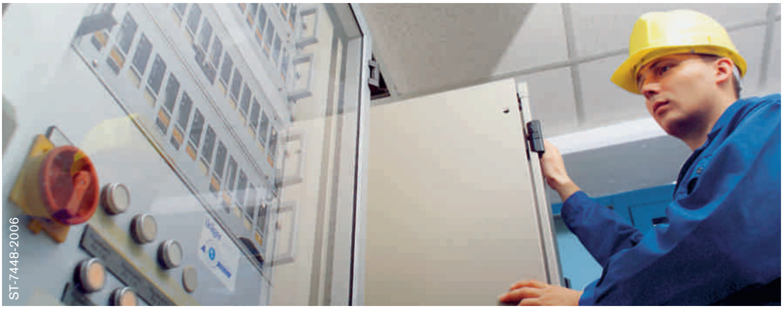
Explosion protection and plant safety

There are flammable substances in almost all industrial areas. Equipment installed in such areas are subject to explosion protection regulations and must be tested and certified.

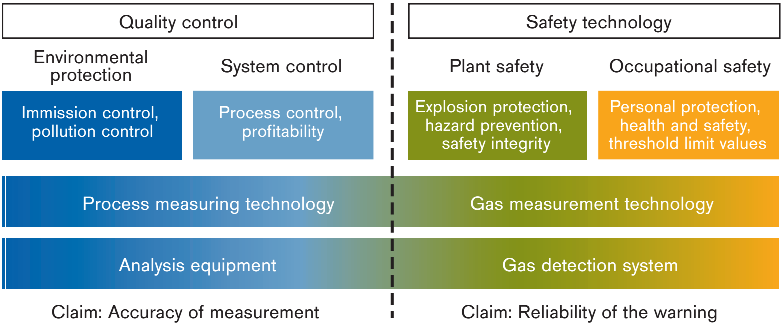
Only through appropriate safety concepts, high availability and fail-safing can gas-warning systems become a reliable protection system.

USAGE AND REQUIREMENTS OF GAS-WARNING INSTRUMENTS AND SYSTEMS

Gas-warning instruments and systems



Gas-warning instruments are essentially products of safety technology and are primarily used to protect workers and ensure plant safety. They are intended to detect dangerous concentrations of gas in time, to warn and possibly also start counter measures before anyone is injured or before there is damage to the plant or environment.



Gas-warning instruments may be portable (or semi-portable) gas-measuring instruments or stationary gas-detection systems. The safety of an area endangered by dangerous gases and vapours depends to a high degree on the reliability of the gas-detection system and in particular on the quality of the sensors being used. In contrast to sensors in portable devices, stationary sensors and their electronics must be continuously operational, all year round, 24 hours a day – similar to a fire extinguisher – just to be available in the rare case of a gas leakage. These sensors are used to some extent under extreme environmental conditions, such as e.g. -50 °C, at 65 °C and high humidity or even very dry environments, in outdoor applications exposed to rain, storms and snow as well as in the hot desert, through electromagnetic disturbances or strong vibrations, etc. And of course, through all of this, their explosion protection capabilities may not be compromised and any influences on the measurement quality only minimal. As the graph shows, there is a fluent crossover from gas-detection technology and process measuring technology. Although developed as a product of safety technology, there are certain gas-detection transmitters today that are such excellent measuring instruments that they are also increasingly being used in the field of process measuring.

USAGE AND REQUIREMENTS OF GAS-WARNING INSTRUMENTS AND SYSTEMS

Requirements of gas-detection instruments

As safety technology products, gas-detection devices or gas-warning systems for industrial use, apart from complying with statutory requirements (electrical safety, explosion protection, electromagnetic compatibility), also fulfill other requirements, so that even under harsh conditions the product's quality and the reliability of the warning system remains intact.

Explosion protection standards:
Design requirements make sure that devices will not act as a source of ignition. Worldwide accepted standards are issued by e.g. CENELEC (ATEX), IEC, CSA, UL, GOST, etc.

Electromagnetic compatibility according to EN 50 270:
Test standards ensure that the device does not produce conducted interference or interfering radiation, but also can particularly withstand conducted interference (surges or bursts) and high-frequency irradiation (80 MHz to 2 GHz at field strengths of up to 30 V/m) and impulse discharge without their reliability of the device being compromised. The relevant test standards are based on the IEC 61000 series.

Climate, vibration and impact, e.g. according to IEC 60028:
Temperature cycles (up to 70 °C), dry and damp (with condensation) over several days as well as a cold test. In addition, defined functionality tests and a test of the insulation resistance. Vibration testing with up to four-fold acceleration due to gravity for 90 minutes per axis at pre-determined resonance frequencies without functions being adversely impaired.

Measuring performance:

Compliance with predetermined measuring quality has to be met even under extreme environmental conditions (temperature, pressure, wind, humidity, vibration, etc):
EN 60079-29-1 - for flammable gases and vapours
EN 45 544 - for toxic gases and vapours

Digital communication according to EN 50 271:

Transmitter and controller are usually steered by microprocessors nowadays. Both hardware as well as software need to comply with requirements regarding the system's reliability.

Seagoing vessel approvals:

Requirements of the classification societies e.g. Det Norske Veritas (DNV), Lloyds Register of Shipping (LRS), Germanischer Lloyd (GL), Bureau Veritas (BV), etc.

USAGE AND REQUIREMENTS OF GAS-WARNING INSTRUMENTS AND SYSTEMS

Suction and sampling

There are many reasons for not placing the sensor directly at the location where the gas to be detected may occur. Continuous collection solves that problem and even has its advantages. One can prepare the collected sample (filter, temper, dry and remove condensate), compensate for pressure changes, change over to monitor further collection points and also feed the test gas to the sensor automatically.

Zone entrainment

Sample intake from an Ex area means that the Ex zone (mostly Zone 1) is spread into a safe environment. As there are no means of explosion protection in the safe area, ignition could occur. This can be avoided by using flame arrestors in the aspiration lines. Flame arrestors do not inhibit the ignition but they can at lease prevent a flash back into the Ex area.

Sampling lines

The smaller the diameter of the aspiration line, the higher the pressure drop; the greater the diameter, the longer the response time. A good compromise is a line with a 4 mm diameter and a flow of about one to two litres per minute.

Pre-sampling

Using a stronger pump (10 to 20 L/min) allows you to pre-sample over very long aspiration lines and you can use a second, smaller gas sample pump (ca. 1 L/min) to deliver the gas sample to the sensor.

Pump and sampling-line monitoring

For safety purposes, you should keep in mind that sample collection increases the response time and the entire sampling line needs to be monitored for proper functioning. This is mostly done using a flow meter with alarm contacts that triggers an alarm in the event of a blocked aspiration line or pump failure. If filters or condensate traps are used, these naturally need to be changed or emptied regularly.

Material and surface adsorption effects

Teflon* (PTFE), Viton** and stainless steel have proven to be good tubing materials. It is important to keep in mind that some gases tend toward increased adsorption on material surfaces, thus distorting the results of ppm measurements.

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* Teflon® is a registered trademark of DuPont.

** Viton® is a registered trademark of DuPont.

USAGE AND REQUIREMENTS OF GAS-WARNING INSTRUMENTS AND SYSTEMS

Explosion protection

Very frequently, flammable substances and sometimes also flammable dusts are involved in industrial processes. In these areas, flammable gases and vapours can be released as a result of processes (e.g. from relief valves) or also due to unforeseen incidents (failures). In the interests of safety, these hazardous areas are declared to be Ex areas (Zones) and only equipment that is certified with a reliable type of ignition protection may be installed.

Explosion protection is regulated worldwide. The basis of these standards, according to IEC, CENELEC (Europe) and NEC 505 (North America), is very similar and is established on the “3-zone concept”, which is becoming more widely accepted in the USA.

Zone according to IEC, NEC 505 and CENELEC	Dangerous, explosive atmospheres are present...
Zone 0	constantly, regularly or long-term
Zone 1	occasionally
Zone 2	seldom and for short periods

The typical American explosion protection concept according to NEC 500 is still based on the 2-division concept:

Division according to NEC 500	Dangerous explosive atmospheres are present...
Division 1	constantly or occasionally
Division 2	not likely to exist

According to IEC, NEC 505 and CENELEC, there are seven standardised types of protection for electrical equipment in Zone 1, while in North America (USA/Canada), according to NEC 500, there are only three types of ignition protection for Division 1:

Types of ignition protection according to IEC, NEC 505 and CENELEC	Comparable protection according to NEC 500
Flameproof encapsulation	Pressure encapsulation (Explosion proof)
Molded encapsulation	–
Sand encapsulation	–
Oil encapsulation	–
Forced ventilation	Purged / pressurised
Increased Safety	–
Intrinsic safety	Intrinsically safe

Explosion protection types such as sand and oil encapsulation are rarely used today in detection and control technology and play no role in gas-detection technology. Forced ventilation, e.g. a continuous flush with pressurised air is a typical type of ignition protection for large equipment and control or switch cabinets. The standardised labelling for equipment, e.g. Ex de IIC T4 informs the expert of the applicability in the designated hazardous area.

USAGE AND REQUIREMENTS OF GAS-WARNING INSTRUMENTS AND SYSTEMS

Type of protection: intrinsic safety

For products of measurement and control technology, which have relatively low power consumption, intrinsic safety is the most elegant method of explosion protection. Elegant, because the product is designed so that even in the case of a first or second failure it is ensured that neither sparks of sufficient energy nor surfaces of sufficient temperature can occur – so there is never any risk of ignition.

Electrical discharges must have a certain minimum energy **(ignition energy)** otherwise they will not be able to ignite even the most flammable mixture of a given flammable gas with air – hence, no other arbitrary mixture of this gas with air can also be ignited.

Also, for a given gas, the surface temperatures of electric or electronic components shall not exceed a certain temperature **(ignition temperature).** Therefore, if the electronic circuits of a product are designed accordingly and the stored electric energy (i.e. effective capacity and inductivity) as well as electrical power (i.e. electrical current and voltage) are limited to certain maximum values, this electronic circuit cannot act as an ignition source; the product is then intrinsically safe.

There is an important accessory for this: when intrinsically safe current circuits leave the hazardous area, they need to be protected by so-called safety barriers from incorrect voltage. **Safety barriers** have at least a microfuse, resistors for current limitation and Zener diodes for voltage limitation.

Intrinsically safe products are marked by an “i”.

Their design is lightweight and simple – and in principle, they may be opened and worked on under voltage or cables may be disconnected and sensors replaced because igniting sparks cannot occur under any circumstances.

USAGE AND REQUIREMENTS OF GAS-WARNING INSTRUMENTS AND SYSTEMS

Type of protection: flameproof encapsulation

Flameproof encapsulation (originally pressure-tight encapsulation) is the oldest type of protection, having been used in the early mining industry since the beginning of the last century. The international marking “d” for Druck (= pressure) refers to the German origins of this method of explosion protection. Compared to intrinsic safety, flameproof encapsulation is a heavy and purely mechanical method of avoiding the ignition of an explosive atmosphere.

You simply let it happen inside the enclosure and thereby reliably avoid a flashback. Housings for flameproof encapsulation must therefore be designed so that they will withstand the pressure from the explosion on the inside. The greater the housing's volume, the higher the potential explosion pressure and the more robust the housing must be.

If flammable gases penetrate into the interior of the housing, an ignition resulting from the electronic circuits found inside (which also may produce sparks) can’t be ruled out. If an ignition occurs, the enclosure will withstand the explosion pressure and the explosion pressure is relieved by the “joints”.

These mostly metallic joints with a predetermined surface area (gap dimensions) have a very important function: hot gases flowing along these joint paths are cooled down below their ignition temperature – a very effective flame extinguisher.

With this type of standardised protection, a potential flame in the enclosure’s interior cannot flashback into the hazardous area.

Flameproof encapsulation products are heavy and may not be opened under voltage (official permission is required for servicing such equipment). Flameproof encapsulated equipment can be connected in three ways:

1. **Conduit piping:** The electrical wiring is laid in approved pipelines that also have flameproof encapsulation. The pipes are screwed directly into the designated, conical compression fitting of the product.
2. The cable is led out via an approved **flameproof cable gland.** Disadvantage: the explosion protection is established only after the installation on-site.
3. The connecting cable is connected via an approved **terminal box with the increased safety** ("e") designation.

USAGE AND REQUIREMENTS OF GAS-WARNING INSTRUMENTS AND SYSTEMS

ATEX 95 – Directive 94/9/EG

Also known as ATEX 95 (previously ATEX 100a), mandatory since 1 July 2003. Equipment and protective systems for use in potentially explosive areas (national implementation: Explosion Protection Regulation ExVO). Concerns the requirements for the quality of equipment used in potentially explosive areas.

Device categories and safety requirements:

Device group	Category	Safety
I (Mining)	M1	very high
	M2	high
II (Other hazardous areas)	1	very high
	2	high
	3	normal

Free trade in goods within the EU:

CE 0158

Notified body for production and quality

Meets EU requirements

Marking (as defined by ATEX):

Ex II 2 GD

Type of explosive atmosphere:
G: gas, vapour, mist; D: Dust

Category

I: Mining, II: everything except mining

Complies with Directive 94/9/EG

Explosion protection

Ex ib IIC T4

Temperature class

Explosion group: I: Mining, II: everything except mining
with ia, ib, d and n: sub-groups IIA, IIB and IIC

Ignition protection type class

Explosion-protected equipment

EC type-examination certificate

TPS 04 ATEX 1003X

X: Special conditions
U: Ex component

Certificate number

Complies with Directive 94/9/EG

Year of the EG type-examination certificate

Notified body for EG type examination

USAGE AND REQUIREMENTS OF GAS-WARNING INSTRUMENTS AND SYSTEMS

ATEX 137 – Directive 1999/92/EG

Also known as ATEX 137 (previously ATEX 118a), mandatory in the EU since 30 June 2006. Concerns the employers' minimum health and safety requirements in potentially explosive areas.

Zone definitions:

Gas, vapour	Dust	Explosive atmospheres are present...
Zone 0	Zone 20	continuously, long periods or frequently
Zone 1	Zone 21	occasionally
Zone 2	Zone 22	infrequently and for a short time only

Selection of equipment (this table links ATEX 95 categories with ATEX 137 zones):

Permitted use	Gas, vapour (G)	Dust (D)
Instruments in Category 1	Zone 0, 1, 2	Zone 20, 21, 22
Instruments in Category 2	Zone 1, 2	Zone 21, 22
Instruments in Category 3	Zone 2	Zone 22

Example: In Zone 21, where explosive atmospheres caused by dust can occur, the equipment used must be labelled **II 2D** or **II 1D**.

Necessary measures:

- Assessment of explosion risk
- Classification of the hazardous areas into zones
- Designation of the hazardous areas with the triangular warning sign “Ex”
- Operating company’s safety policies
- Explosion protection document
- Employee qualifications
- Criteria for approval for activities in the hazardous area

Guideline for hazard prevention:

- Avoid the formation of explosive atmospheres. If this is not possible:
- Prevent the ignition of explosive atmospheres. If this is not possible:
- Reduce the harmful effects of the explosion to a tolerable minimum.

USAGE AND REQUIREMENTS OF GAS-WARNING INSTRUMENTS AND SYSTEMS

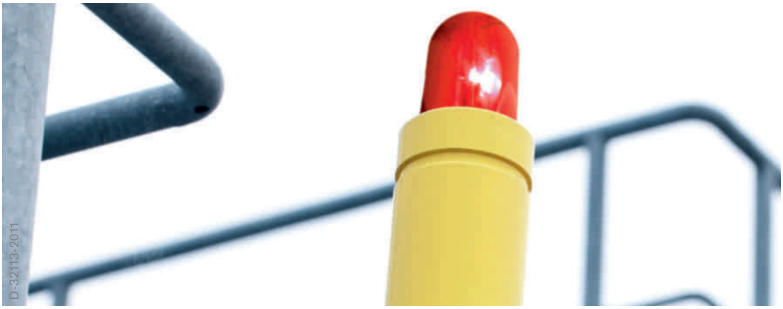
Safety integrity – SIL

The term safety integrity has become a buzzword through the technologically-based and automated safety technology. Stationary gas-detection technology is also no exception here. The safety integrity level (SIL) is an objective measure for judging the reliability of a risk reducing facility.

- Wherever there is a potential danger for people, assets or the environment, it is necessary to achieve a certain degree of safety by means of risk-reducing measures. If such measures are achieved automatically by so-called electric, electronic or programmable electronic systems, it is called “functional safety”.
- Such systems, frequently called protective systems or safety relevant systems, perform a safety function and must have adequate reliability (integrity) with respect to the actual risk.
- However, such systems can malfunction due to randomly occurring failures. If they fail, they must at least go into a safe state and need to be repaired immediately. This, however, implies that the occurrence of such a failure is detectable at all.
- A high percentage of the possible failures (which are identified by an “FMEDA”) can be recognised through failure monitoring (diagnostic facilities), so that in case of a detectable failure the system can be offset into a safe state (fail safe).
- Statistically, there will always remain a very small fraction of accidental failures that cannot be detected automatically. Although they occur rarely, these “dangerous undetected failures” (or “DU failures” for short) still impede the execution of the safety function.
- From the ratio between the possibility of encountering a DU failure to all possible failures, the degree of Diagnostic Coverage (DC) and the Safe Failure Fraction (SFF) can be calculated. They may not, depending on the requirements, go below predetermined percentages.
- Through sensible system concepts (in particular also redundancies), periodically repeated function tests and preventive measures the probability of the occurrence of a DU failure can be further decreased.
- The remaining residual risk can be assessed statistically and classified. This results in four different safety integrity levels, SIL1 to SIL4.

USAGE AND REQUIREMENTS OF GAS-WARNING INSTRUMENTS AND SYSTEMS

Alarm philosophy



What do you do in the event of an alarm? Gas-detection systems are designed to trigger timely alarms, to inform operators about the alert and to initiate counter-measures to prevent a dangerous situation occurring. This mostly happens automatically but can also be achieved organisationally by developing an alarm plan. Should an alarm be triggered, it is the operator's responsibility to respond adequately.

The concept of a gas-detection system is always:
to recognise gas danger, to react and to avert.

Main alarm

In principle, exceeding only one main alarm threshold is sufficient. This achieves the safe state by protecting the hazardous area (visible / audible alarm and evacuation) or by shutting off gas supply or by disabling the ignition sources, requiring the donning of personal protective equipment, respirators, etc. This is a safe but difficult, namely uneconomic measure – because the entire process is shut down.

Pre-alarm

This can possibly be avoided by using a pre-alarm that is activated at lower concentrations than that of the main alarm threshold. With the pre-alarm, automatic counter measures can prevent the need for the main alarm. If the pre-alarm is tripped, the situation can be taken care of by effective ventilation keeping the gas concentration from rising excessively and the main alarm threshold from being reached. This is ideal because **a pre-alarm can be used to control a dangerous situation without a process shutdown.** It is in the interest of the operator to design counter measures that are so effective that the main alarm will most likely never be triggered: **properly designed, gas-detection systems will only rarely if ever reach the main alarm.**

Malfunction alarm

Malfunction alarms indicate that the system is partly or entirely inoperative and cannot react properly in the event of a gas release. The same preventive measures need to be taken in the case of a malfunction alarm as in the case of a main alarm, in other words a safe state has to be initiated.

USAGE AND REQUIREMENTS OF GAS-WARNING INSTRUMENTS AND SYSTEMS

Sensor positioning


MT-467-2008

The reliability of a gas-detection system not only depends on its features, but also on how it is installed and operated. Understandably, sensors can only detect a gas leakage if the sensor is surrounded by that gas. A gas-detection system can be be useless if the sensors have not been positioned correctly.

Leaks are characterised by when gases, frozen (liquefied) and/or pressurised, are released into the surrounding air and mix with it. Their concentration decreases and the gas dispersion depends more on the temperature conditions and air currents than on the density of the gas in its pure form.

Three rules of thumb:

- There are only three flammable gases that are considerably lighter than air: hydrogen, methane and ammonia. Mixtures of these gases with air generally rise upwards.
- Vapours of flammable liquids are always heavier than air – they flow downwards, as long as they are not disturbed by convection.
- Independent of the density of the gas, gas concentrations of less than 1,000 ppm in air are virtually the same weight as air. Dispersion of concentrations such as this follow the existing air current.

Positioning strategy:

The best method for detecting leaks is to place the sensors as close as possible to the areas where potential leaks may occur. Such points of leakage are pumps, valves, flexible piping, connections, flanges, shut-off devices, balancing bellows, etc. If such locations cannot easily be identified, sensors need to be distributed over the entire hazardous area (area monitoring). Particular care must be taken that, under the local circumstances, the gas to be detected can also actually reach the sensor. The local circumstances of areas to be monitored are individually so different that there are useful guidelines for positioning sensors (e.g. the EN/IEC 60079-29-2) but no mandatory regulations.

3.2 Sensors and measuring principles


D-13504-2010

SENSORS AND MEASURING PRINCIPLES

Introduction

Sensors for the detection of gases and vapours are transducers that make use of certain properties of gases to convert them into an electrical signal.

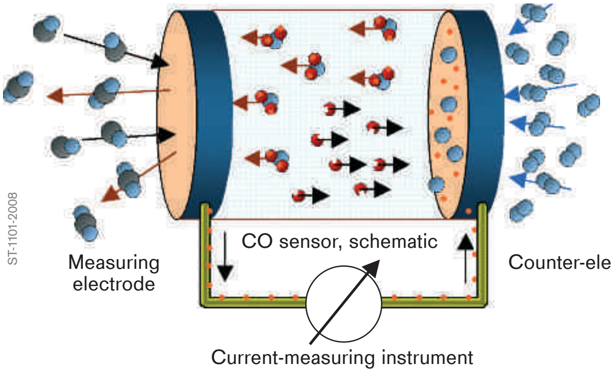
In industrial gas-detection technology, three measuring principles in particular have taken precedence: electrochemical sensors, catalytic bead sensors and infrared sensors.

SENSORS AND MEASURING PRINCIPLES

Measuring principle of electrochemical sensors

Very many toxic gases are also very reactive and will change their chemical compositions under suitable conditions. The electrochemical sensor is a micro-reactor, which produces a very small but still measurable current in the presence of such gases. Like in a battery, electrochemistry comes into play because the chemical reaction produces electrons.

An electrochemical sensor consists of at least two electrodes (measuring electrode and counter-electrode) that have contact with each other in two different ways: on the one hand via an electrical conductive medium (electrolyte: a pasty liquid as ion transporter);, on the other hand, via an outer electric current circuit (an electron conductor):



The electrodes are made of a special material that also has catalytic characteristics so that certain chemical reactions take place at the “3-phase boundary”, where gas, catalyst and electrolyte are present. The “electron grabber” oxygen, required for the reaction, comes from the ambient air; other “electron grabbers” are, for example, chlorine, fluorine, ozone or NO_2. Thus, current in the sensors being used for these gases flows in the reverse direction. Such currents can be measured by a micro-amp meter.

CO molecule, target gas, enters the measuring electrode

CO_2 molecule, reaction product, leaves the measuring electrode

H_2O molecule, part of the electrolyte

H^+, hydrogen ion with positive charge because one electron is missing

O, oxygen atom, aggressive, grabs electronsone electron is missing

O_2, oxygen molecule, decomposes on the counter-electrode atomically

Electron, flowing electrons are measurable as electric current

SENSORS AND MEASURING PRINCIPLES

Electrochemical sensors

Dräger electrochemical sensors can detect well over a hundred gases and vapours. Some of these sensors react very specifically to the target gas while others are typical gas-group sensors that can detect a number of reactive gases.

Dräger's electrochemical sensors are equipped with three electrodes: a measuring electrode, counter-electrode and a reference electrode. The sensor's measuring performance is improved by means of a sensor bias voltage and is kept constant by the reference electrode and an electronic control circuit (a so-called potentiostat circuit). Additionally there is a temperature measuring element in the interior of the sensor because electrochemical processes are extremely temperature dependent and need to be compensated accordingly.

Through the external circuitry of the sensor, and particularly also the temperature compensation and the amplification of the low and noisy sensor current (only a few micro amperes), which produces a 4-20-mA-signal, the electrochemical sensor becomes a gas-measurement transmitter. With this, the following measuring ranges are possible (and are even user-adjustable with e.g. the Polytron 7000):

Measuring gas	Minimum measuring range final value	Maximum measuring range final value
Acidic compounds	3 ppm	30 ppm
Ammonia	50 / 300 ppm	200 / 1,000 ppm
Chlorine	1 ppm	50 ppm
Hydrogen chloride	20 ppm	100 ppm
Hydrogen cyanide	10 ppm	50 ppm
Hydrazine	0.3 ppm	3 ppm
Hydrides	0.3 ppm	1 or 20 ppm
Carbon monoxide	50 / 200 ppm	1,000 / 5,000 ppm
Organic vapours	20 ppm	100 or 200 ppm
Ozone	0.5 ppm	5 ppm
Phosgene	0.1 ppm	1 ppm
Oxygen	5 vol. %	25 / 100 vol. %
Sulphur dioxide	5 ppm	100 ppm
Hydrogen sulphide	10 / 100 ppm	100 / 1,000 ppm
Nitrogen dioxide	5 ppm	100 ppm
Nitric oxide	30 ppm	200 or 500 ppm
Hydrogen	500 ppm	3,000 ppm
Hydrogen peroxide	1 / 1,000 ppm	50 / 7,000 ppm

The electrochemical sensor requires such low electric power that it is intrinsically safe to operate. In this case, heavy, flameproof enclosures are not required and sensor replacement can simply be carried out on site.

SENSORS AND MEASURING PRINCIPLES

Measuring principle: catalytic bead sensors

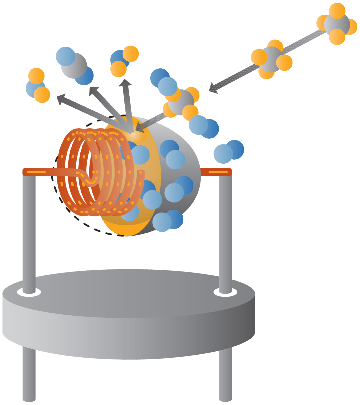
Under certain circumstances, one can oxidise flammable gases and vapours with atmospheric oxygen through the release of the "heat of reaction". Suitably tempered catalyst material, whose temperature is also measurably increased by the heat of reaction, is used for this. This slight increase in temperature is a measure of the gas concentration.

Pellistors are tiny and very porous ceramic beads (approximately 1 mm in diameter), with an embedded platinum coil. An electric current flows through the platinum coil, heating up the pellistor to a few hundred degrees Celsius.

If the pellistor contains suitable catalytic material, its temperature will rise in the presence of flammable gas and the resistance of the platinum coil will rise accordingly. This change in resistance can be electronically analysed.

To eliminate changes in the surrounding temperature, a second pellistor is used. It is very similar to the first pellistor, except that it does not react to gas (e.g. it does not contain any catalyst material or is otherwise inhibited).

A sensor circuit arises in a "Wheatstone bridge circuit", which can detect the presence of flammable gases and vapours in air, for the most part independent of the ambient temperature.



On a hot pellistor, gaseous methane supplied from the outside is oxidised with the help of the activated atmospheric oxygen present in the porous material. Apart from water vapour and carbon dioxide, measurable reaction heat is generated.

$CH_4 + 2\ O_2 \Longrightarrow 2\ H_2O + CO_2$ + reaction heat

SENSORS AND MEASURING PRINCIPLES

Catalytic bead sensors

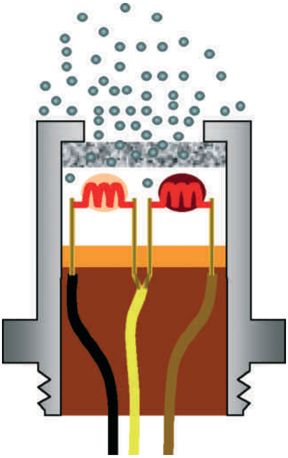
One pellistor alone is not suitable for detecting flammable gases and vapours. For a usable catalytic bead sensor, a second pellistor to compensate for environmental influences (particularly temperature) and integrated measures for ignition protection (flame proof encapsulation and sinter plate) are needed.

The compensator pellistor is built very similarly to the active pellistor but does not contain catalyst material so that no gas can be oxidised: if the ambient temperature changes, the resistance of both the pellistors will change; if gas is present, only the resistance of the active pellistor will change.

Since the pellistors of the catalytic bead sensor are heated to about 450 °C, it can act as an ignition source itself if the LEL is exceeded. This is prevented by using a metal sinter disc: if an ignition takes place in the interior of the catalytic bead sensor, the sensor's housing withstands the explosion pressure and the flame is cooled down to below the ignition temperature of the gas. Thus it is ensured that no flame penetrates the outside area – these are precisely the characteristics of flameproof encapsulation.

Catalytic bead sensors are operated with an electronic circuit called a Wheatstone bridge, which is suitable to convert very small resistance changes into a measurable voltage.

Depending on the position of the second half of the measuring bridge, suchs catalytic bead sensors can be connected to the control centre by means of very long cables or they can also be built directly in a transmitter.



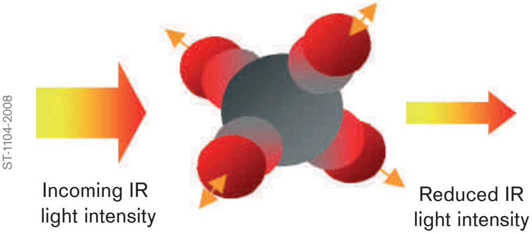
The active pellistor and the compensator are placed in a flameproof encapsulated housing. The gas makes its way through the sinter disc into the interior of the sensor where it comes into contact with the active pellistor.

SENSORS AND MEASURING PRINCIPLES

Measuring principle: Infrared sensor

When considering the broad range of flammable gases and vapours, you realise that most of these substances are chemical compounds consisting primarily of carbon, hydrogen, oxygen and sometimes nitrogen. These “organic compounds” are classified as hydrocarbons. Hydrocarbons have special properties, which come in handy when using infrared measurement technology.

All gases absorb radiation in a characteristic manner and some do so even in the visible range (wavelength 0.4 to 0.8 micrometers). This is why chlorine is green-yellow, bromine and nitrogen dioxide are brown-red, iodine is violet and so on. However, these colours can only be seen at rather high (lethal) concentrations.
Hydrocarbons absorb radiation of a certain range of wavelengths, from approximately 3.3 to 3.5 micrometers. Since oxygen, nitrogen and argon do not absorb radiaton, this property of hydrocarbons can be used to advantage of measurement technology.



A methane molecule excited to vibrate absorbs energy

CH_4 + energy ==> CH_4 (excited)

An optical system containing a mixture of gaseous hydrocarbons such as methane or propane would attenuate the intensity of radiated infrared in a predictable way. And this attenuation depends on the concentration of any given gas.

Air: Infrared passes through without being attenuated – no reduced intensity, no measuring signal

Gas: Infrared passes through and is attenuated – intensity is reduced corresponding to the concentration.

This is the principle behind an infrared measuring instrument, whereby the correlation of the decrease in intensity to the concentration of gas present in the container is produced by the so-called calibration process: a defined gas concentration will always produce the same intensity reduction and thus always the same measuring principle.

Most of the flammable gases and vapours are hydrocarbons, and hydrocarbons are almost always detectable by their characteristic infrared absorption.

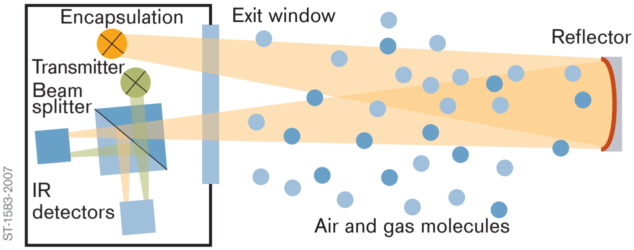
SENSORS AND MEASURING PRINCIPLES

Infrared transmitters

The measuring principle is simple: hydrocarbons absorb infrared radiation (IR) in the wavelength range of approximately 3.3 to 3.5 micrometers (µm), depending on the absorption spectrum of the gas under consideration. However, the attenuation of infrared radiation is very small and a challenge for measuring technology. And, unfortunately, the reduction of intensity can also occur due to other circumstances, e.g. due to contaminated optics or reduction of the infrared radiation.

The source of radiation for an infrared sensor is a flashing, incandescent lamp operated at a low voltage, generating radiation that has a high portion of infrared. This radiation hits a beam splitter (through an infrared permeable window), which distributes the radiation to two infrared detectors, the “measuring and reference detectors”. One detector consists of an encapsulated pyro-electric crystal, which converts the received radiation energy into a measurable voltage. However, the detectors are different because of their optical interference filters: the crystal of the measuring detector for example, only receives radiation wavelengths of 3.4 µm, and the reference detector only of 4.0 µm. Gases do not absorb in the 4.0 µm range. So, if both the detectors detect a reduced radiation energy, gases cannot be the cause! By means of the reference detector, it is therefore possible, to a certain extent, to make the measurement insusceptible to contamination of the optics and even to request preventive maintenance automatically.

Infrared transmitters are equipped with these or similar sensors. The measuring signal of both the detectors is conditioned accordingly and is finally available as a 4 to 20 mA signal. Transmitters are favoured in industrial measurement technology due to their long lifetime. In contrast to the electrochemical and catalytic bead sensors, the detectors of IR sensors do not come into contact with the gases being measured. As long as there is no condensation - and this is inhibited by heated surfaces - IR transmitters perform so excellently that they can be found more and more even in process-oriented industry applications.



IR sensor, schematic

SENSORS AND MEASURING PRINCIPLES

Diffusion-controlled sensors

The high velocity of gas molecules is the reason that gases expand quickly and also mix quickly with other gases. As long as there are local concentration differences, the process of mixing is incomplete and does not come to an end.

Such concentration differences can also act as a micro pump. If the concentration difference is kept constant, there will be a continuous flow of molecules into the direction of lower concentration – and this effect is used for sensors in gas-detection technology. The term “diffusion-driven sensors” is used.

The trick: in the case of the catalytic bead sensor and the electrochemical sensor, the target gas is broken down by the chemical reaction, which is why we have a gas concentration of nearly zero directly at the place of reaction. This is far less than in the ambient area and a zone of depletion is created. Because of this forced concentration difference, molecules of this gas flow continuously into the sensor's reaction area.

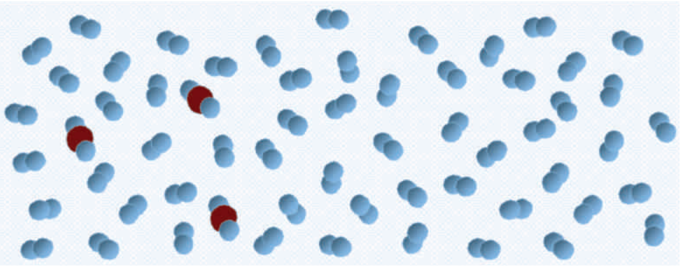


Illustration: Due to the molecular movement, “nature does not rest” until the three large molecules are homogeneously dispersed over the entire volume. Once uniformly distributed, the diffusion process stops.

Convection to the sensor, diffusion in the sensor

While gas essentially reaches the sensor by means of natural convection, the penetration into the sensor’s interior via a sinter disc or dust filter is more of a diffusion controlled process, because pores contain calm air where no convection takes place. The pores themselves do not inhibit gas penetration, rather the calm air: if the gas molecule was as large as a pea, a sinter or filter pore would have a diameter of between 100 to 1,000 meters!

Diffusion-controlled sensors do not need a pump.

SENSORS AND MEASURING PRINCIPLES

Open-path detectors

If you think of an infrared sensor with an optical path extended multiple times, you would have a gas-detection system with an open measuring path, as gas molecules passing through the measuring path cause measurable IR absorption. Gas-detection systems such as this are like a light barrier for gas molecules. And this is true for path lengths of up to 200 meters!

The measurement result of an open-path measurement is somewhat unusual. While we can assume that the optical system of an infrared sensor is filled homogeneously with a defined gas concentration, this is never the case with a long measuring path. Basically, you can't differentiate at all between a high gas concentration along a small part of the open path or only half of the concentration over a section that is twice as long. In both cases the measuring signal is the same because each molecule within the path contributes to the measurement result – independent of its distribution. However, in certain applications the probability that a gas cloud drifts through the open path detector is higher than the probability of it being detected by a point detector. For the sake of safety, you forsake the usual concentration measurement in favour of the higher likelihood of detection.

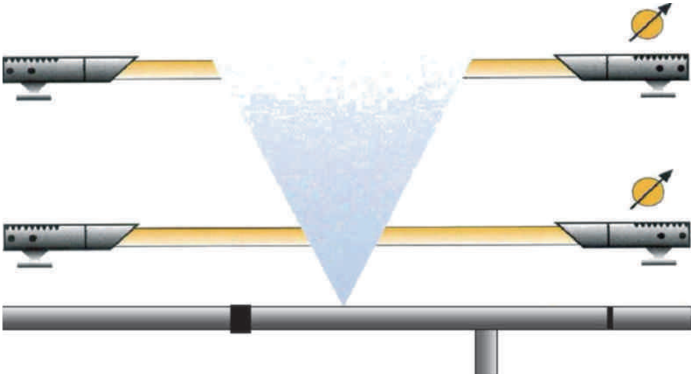


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Illustration: As long as the gas cloud stays in the open path, it delivers the same signal, and that's independent of whether it's diluted by air or not: an open path measuring system counts the molecules, so to speak, and the distance between them doesn't make a difference.

It is said that an open-path detector is more of a reliable gas-hazard detector than a gas-measuring instrument. The information "there is gas present" for applications with a high potential hazard (e.g. in natural gas exploration) is considered sufficient reason to activate safety-related counter measures.

SENSORS AND MEASURING PRINCIPLES

4 ... 20-mA transmitter

A sensor for gas-detection is not quite sufficient for technical gas-detection. The sensor signals need to be electronically conditioned, compensated for temperature and locally displayed for calibration purposes. Measuring ranges need to be configured – for which a power supply is obviously needed.

It is now widely accepted that gas-detection transmitters are operated with 24 V direct current – whereby this voltage may vary within wide limits, meaning for example, between 16 and 30 volts. The transmitter's electronics convert the sensor signal into an output current, so that with clean air (zero point) at the sensor, a current of 4 mA flows to the control unit, while it is 20 mA at full-scale deflection.

If the cable between the transmitter and controller is cut, no current will flow - which can be recognised by to the control center. Moreover, signals lower than 3.8 mA or higher than 20.5 mA are not interpreted as measuring signals but as special signals to indicate, for example, under-range (negative measuring values) or over-range and also certain other maintenance signals. The 4 to 20 mA signal is an industry standard worldwide and in contrast to voltage signals it is independent of cable resistance, more importantly low-resistance and relatively immune to interference.

Transmitters with electrochemical sensors have such low power consumption that they can be operated with even less than 4 mA and, depending on the gas concentration, can draw an additional current of 4 to 20 mA from the power supply. Only two wires are needed for the power supply and the measuring signal: the “2-lead connection”. Unfortunately, three wires are required for higher performance (catalytic bead and IR sensors).

A symmetrical, frequency modulated signal of ±1 mA can be modulated on the 4 to 20 mA signal to exchange additional digital information between the control centre and transmitter. This is the HART signal, which can also be used to address certain transmitters both specifically and digitally, and can request a protocol of their current measurement data. Several HART-compatible transmitters can communicate on only one 2-core communication cable.

Digital communication, be it via HART or the RS 485 interface, gives the operator the possibility to inquire as to the transmitter’s “well-being” remotely and undertake preventive maintenance measures based on the results.

SENSORS AND MEASURING PRINCIPLES

Calibration

Gas sensors do not measure gas concentrations directly; rather electrochemical sensors measure electron flow changes, catalytic bead sensors a resistance change and infrared detectors a change in radiation intensity (in the near infrared range). These changes always refer to the normal condition (clean air), which is called zero point because no gas is present. It is only through the process of the known as calibration, which means the determination of a fixed correlation between gas concentration and measurement signal, that you get a gas-measuring instrument from a gas sensor.

Calibration is extremely important because, understandably, gas-detection devices cannot measure correctly when they have been calibrated incorrectly. While zero calibration is usually rather simple because often the surrounding air can be used for this purpose, calibrating sensitivity is not so straight-forward.

As electrochemical sensors often detect reactive gases, they also must be calibrated with reactive gases - and reactive gases, even at low concentrations, react with (damp) material surfaces and plastics. Although from a safety point of view, the target gas, i.e. the gas that is to be detected during operation, should also be used for calibration, there are several reasons for using a surrogate test gas for calibration purposes.

If the same detector is to be used to detect a variety of gases, the instrument has to be calibrated to the gas to which it is the least sensitive. This way, one is on the safe side, because the concentration of all other gases will be exaggerated. The sensor's sensitivity to given gases cannot be determined from gas-specific data, but rather exclusively by the measurements of such sensors. To get good results, calibration should always be carried out as closely as possible to the conditions that can be expected during operation.

Calibration chamber for flammable liquids

In order to obtain given vol. % LEL concentrations, it is recommended to use a "calibration chamber" into which a certain calculable quantity of fluid (e.g. 100 micro litres) is injected. After complete evaporation, a concentration of e.g. 50% LEL is formed for calibration.

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