

# **Guide to Sensors and Measuring Principles**

## **Sensors and Measuring Principles**

Sensors for the detection of gases and vapours are transducers making use of certain properties of gases for the conversion into a suitable electrical signal.

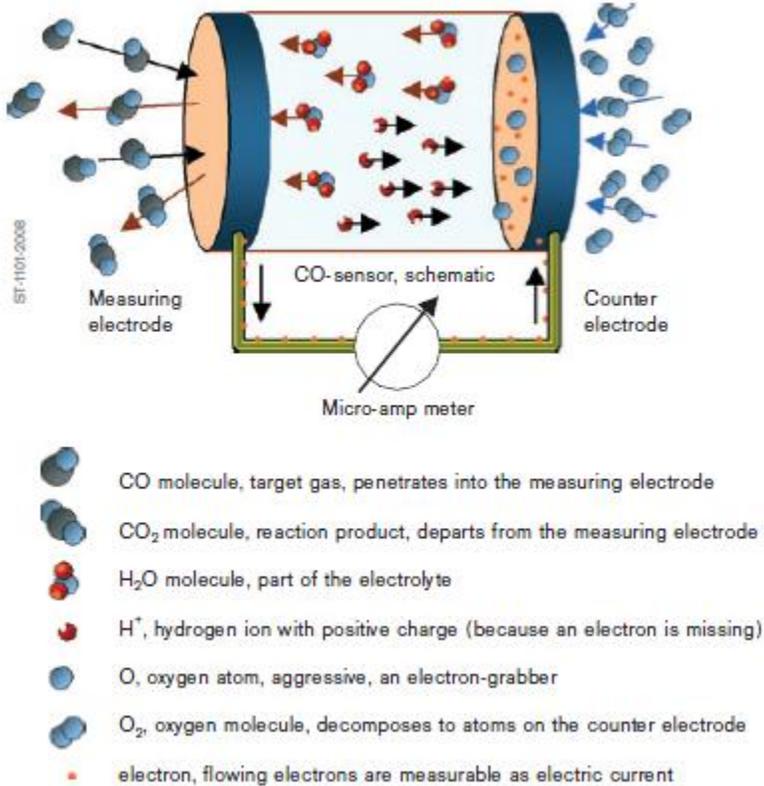
Especially three measuring principles have become mainstream in the recent decades of industrial gas detection: Electrochemical sensors, catalytic bead sensors and infrared sensors.

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## Measuring Principle Electrochemical Sensors

Many toxic gases are also very reactive and under suitable conditions they change by chemical reactions. The electrochemical sensor is such a micro-reactor, which at the presence of reactive gases produces electrons just like a battery. The flow of electrons is a very low but measurable electric current.

An electrochemical sensor consists of at least two electrodes (measuring electrode and counter electrode) which have electrical contact in two different ways: On the one hand via an electrical conductive medium called electrolyte (a pastylike liquid to transport ions), on the other hand via an outer electric current circuit (a simple copper wire to transport electrons):



The electrodes are made of a special material which also has catalytic characteristics enabling certain chemical reactions to take place in the so-called 3-phase zone, where gas, solid catalyst and liquid electrolyte are present.

The electron grabber oxygen being needed for this reaction comes from the ambient air. Further electron grabbers are known, e.g. chlorine, fluorine, ozone or nitrogen dioxide.

Thus the sensor current of sensors being used for these gases flows in reverse direction. The current can be measured by means of a micro-amp meter.

## Electrochemical Sensors

**More than a hundred of gases and vapours are detectable by electrochemical Dräger sensors. Some of these react very specifically to the target gas, others are typical gas group sensors being sensitive to a lot of different reactive gases.**

Electrochemical Dräger sensors are mostly equipped with three electrodes, a measuring-, a counter-, and a reference-electrode. The sensor's measuring performance is increased by means of a bias voltage being measured and kept constant by means of the reference-electrode and an electronic control circuit (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. Only by the outer electrical circuit of the sensor (especially for temperature compensation and amplification and conditioning of the very low and noisy sensor current - only a few micro amperes) which produces a 4-20-mA-signal, the electrochemical sensor turns into a real gas detector. The following measuring ranges can be realized (user adjustable with e.g. Polytron 7000):

Gas	minimum full scale deflection	maximum full scale deflection
Acidic Compounds	3 ppm	30 ppm
Ammonia	50 / 300 ppm	200 / 1000 ppm
Carbon monoxide	50 / 200 ppm	1000 / 5000 ppm
Chlorine	1 ppm	50 ppm
Hydrazine	0.3 ppm	3 ppm
Hydrides	0.3 ppm	1 / 20 ppm
Hydrogen	500 ppm	3000 ppm
Hydrogen chloride	20 ppm	100 ppm
Hydrogen cyanide	10 ppm	50 ppm
Hydrogen peroxide	1 / 1000 ppm	50 / 7000 ppm
Hydrogen sulfide	10 / 100 ppm	100 / 1000 ppm
Nitrogen dioxide	5 ppm	100 ppm
Nitrogen monoxide	30 ppm	200 / 500 ppm
Organic Vapours	20 ppm	100 / 200 ppm
Ozone	0.5 ppm	5 ppm
Oxygen	5 Vol%	25 / 100 Vol%
Phosgene	0.1 ppm	1 ppm
Sulfur dioxide	5 ppm	100 ppm

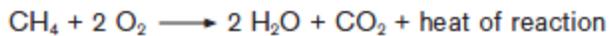
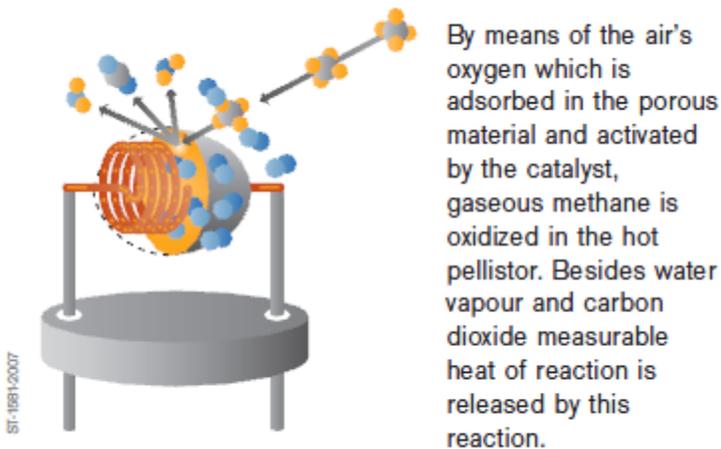
The electrochemical sensor needs very low electric power and can thus be operated intrinsically safe. In this case problems with heavy flameproof enclosures do not apply and sensor replacement at site can be carried out very easily and without hot work permit.

## Measuring Principle Catalytic Bead Sensor

Under certain circumstances flammable gases and vapours can be oxidized by means of the air's oxygen to release heat of reaction. Typically this is achieved by special and suitable heated catalyst material, which slightly increases its temperature by the heat of reaction. This increase of temperature is a measure for the gas concentration.

So-called pellistors are tiny and very porous ceramic beads (diameter approx. 1 mm) embedding a small platinum wire coil. There is an electric current flowing through the platinum wire coil so that the pellistor is heated up to some hundred degrees Celsius.

If the ceramic bead contains some suitable catalytic material, the pellistor's temperature will rise in the presence of flammable gas, and the platinum wire coil's resistance will increase accordingly. This change in resistance in respect to the resistance in clean air is used for electronic evaluation.



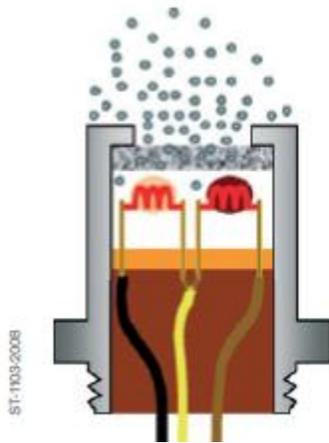
To eliminate influences of changes of the ambient temperature, a second pellistor is used, which is very similar but does not respond to gas, because the pellistor does not contain catalyst material or is inhibited otherwise.

Integrating both the pellistors in a Wheatstone bridge circuit results in a sensor for concentration measurement of flammable gases, to a large extent independent of the ambient temperature.

## Catalytic Bead Sensors

One pellistor alone is not suitable for the detection of flammable gases and vapours. It needs a second one to compensate for environmental parameters (especially temperature and humidity). And it needs to be explosion protected. By means of a flameproof enclosure and a sinter disk a useful catalytic bead sensor results.

The compensator pellistor is built very similar to the active pellistor, but does not contain catalyst material so that gas cannot be oxidized. If the ambient temperature changes, the resistance of both the pellistors will change and there is no bridge signal. However, if gas is present, only the resistance of the active pellistor changes and the Wheatstone bridge is unbalanced. Since the pellistors of the catalytic bead sensor are heated to about 450 °C, it can act as an ignition source if the LEL is exceeded and the ignition temperature of the gas is lower than 450 °C. By means of a sinter disk the following is prevented: If in the interior of the catalytic bead sensor an ignition takes place, the sensor's housing will withstand the explosion pressure and the flame is cooled down below the ignition temperature of the gas, and no flame penetrates to the outside. These are the characteristics of the so-called flameproof encapsulation.



The active pellistor and the compensator are placed in a flameproof encapsulated housing. The gas is penetrating through the sinter disk into the interior of the sensor where it is oxidized by the active pellistor.

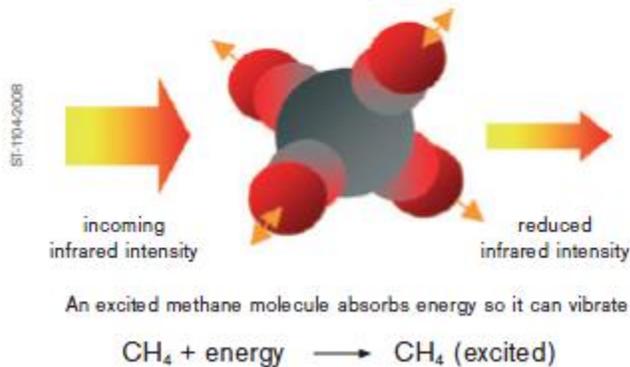
Catalytic bead sensors are operated with an electronic circuit called Wheatstone bridge, which is suitable to convert very small resistance changes into a measurable voltage.

If the second half of the Wheatstone bridge is placed in the controller, the catalytic bead sensor may be connected to controllers by means of very long cables. However, they are short when the sensor is installed in a transmitter.

## Measuring Principle Infrared Sensor

When considering the broad range of flammable gases and vapours one will realize that most of these substances are chemical compounds primarily consisting of carbon, hydrogen, oxygen, and sometimes nitrogen. These so-called organic compounds are called hydrocarbons. Hydrocarbons have special properties which can be used for infrared measurement of their concentration.

All the gases absorb radiation in a characteristic manner, some even in the visible range (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 and lethal concentrations. Hydrocarbons absorb radiation of a certain wavelength range, approx. at 3.3 to 3.5 micrometers, and, since oxygen, nitrogen and argon do not absorb, this can be used for concentration measurement of hydrocarbons in air.



An optical system containing a mixture of e.g. methane or propane in air will attenuate an incoming infrared intensity in a predictable way, and for a given gas this attenuation is depending on only its concentration.

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

**Gas:** Infrared passes by being attenuated, reduced intensity, measuring signal corresponds to the current gas concentration.

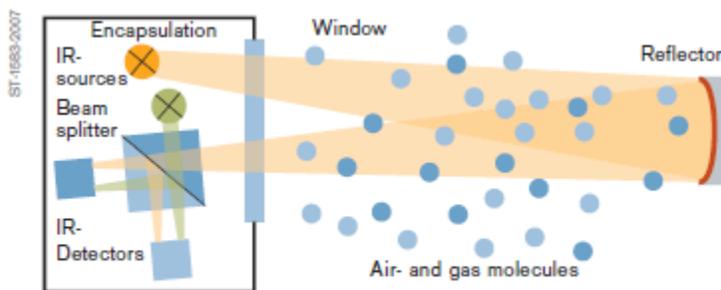
This photometer principle is the basis of an infrared measuring instrument. The correlation of measured intensity reduction on the one hand and the gas concentration in the optical system on the other hand, is made by the calibration process: A defined gas concentration will always produce the same intensity reduction and thus always the same measuring signal.

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

## Infrared Transmitters

The measuring principle is simple: Hydrocarbons absorb infrared radiation (IR) in the wavelength range of 3.3 to 3.5 micrometers ( $\mu\text{m}$ ), more or less, depending on the absorption spectrum of the considered gas. However, the attenuation of the infrared radiation is very small and a challenge concerning the measuring technique. And, unfortunately, the reduction of intensity can also occur by other circumstances, e.g. by contaminated optics or reduction of the infrared radiation source's intensity.

The radiation source of an infrared sensor is a flashing filament lamp, operated with low-voltage, having a high percentage of infrared. Passing an IR-transparent window this radiation is split into two parts by means of a beam splitter, one part for the measuring detector, one part for the reference detector. A detector consists of an encapsulated pyro-electric crystal converting 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 only receives radiation of e.g. 3.4  $\mu\text{m}$ , and the reference detector of e.g. 4.0  $\mu\text{m}$  wavelength. Gases generally do not absorb at 4.0  $\mu\text{m}$ . So, if both the detectors detect a reduced radiation energy, gases surely are not the cause! By means of the reference detector it is possible to make the measurement to a certain degree unsusceptible to contamination of the optics and even to automatically request for preventive maintenance.



IR-Sensor of the Polytron IR type 340, schematically

IR-Transmitters are equipped with IR sensors like this.

The measuring signal of both the detectors is conditioned accordingly and is finally available as a 4 to 20-mA signal at the transmitter's output. Because of their long lifetime IR-transmitters are favoured in the industrial measurement.

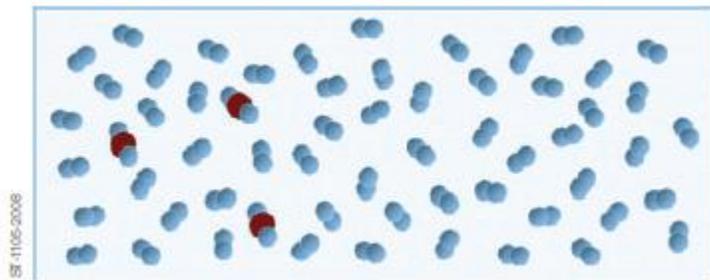
In opposite to the electrochemical and catalytic bead sensors the detectors of IR-sensors do not come into contact with the gases to be measured. As long as there is no condensation - and this is inhibited by heated surfaces - IR transmitters perform so excellently that they can be found more and more even in process industry applications.

## Diffusion Controlled Sensors

**The high velocity of the gas molecules is the cause that gases expand quickly and also quickly mix up with other gases and never separate again. And as long as there are concentration differences in the whole mixture the process of mixing is incomplete and does not come to an end.**

These 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 the lower concentration – and this effect is used for sensors in gas detection technology, the so-called diffusion-controlled sensors.

The trick: With the catalytic bead sensor and the electrochemical sensor the target gas is consumed by chemical reaction, directly on the place of reaction we have a gas concentration of nearly zero, far less than in the ambient area, producing a depletion zone. So there is a forced concentration difference and gas molecules are flowing into the sensor's reaction area.



**Illustration:** Because of the molecular movement the nature does not keep calm until the three bigger molecules are homogeneously dispersed over the entire gas volume. After uniform distribution the diffusion process ends.

Convection to the sensor, diffusion into the sensor While gas essentially gets to the sensor by means of natural convection, the penetration into the sensor's interior via sinter disk or dust filter is rather a diffusion controlled process, because pores contain calm air where no convection takes place. Not the pore walls but the calm air is inhibiting the penetration: If a gas molecule would be as big as a pea, a sinter pore or filter pore would have a diameter of some 100 to 1000 meters!

**Diffusion controlled sensors do not need a pump.**

## Open Path Detectors

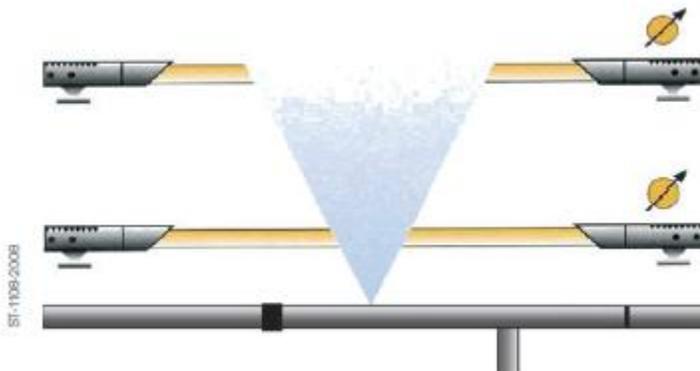
**If you think of an infrared-sensor with an optical path extended for multiple times, this would be a gas detection system with an open path: gas molecules entering this path will cause a measurable IR-absorption. Gas detection systems like this are something like a light barrier for gas molecules. And not only for a few meters, this is true for open path lengths of up to 200 meters!**

The measuring result (reading) of an open path measurement is a little bit unusual. While the optical system of an infrared-sensor can be assumed to be homogeneously filled with a defined gas concentration, this is never the case with a long measuring path.

Basically one cannot differentiate whether there is a high gas concentration along a small part of the open path or half the concentration along twice the path length: In both cases the measuring signal is the same because each absorbing molecule in the path contributes to the measuring signal, independent from their distribution.

However, in special applications the probability that the gas cloud is drifting through the open path is higher than being detected by a point detector.

In the terms of safety: One abandons the usual concentration measurement for the sake of higher detection probability.



**Illustration:** As long as the gas cloud stays in the open path there is a measuring signal, independent of the dilution with air. We may say an open path detector is a molecule counter independent of their distances.

So, an open path detector is rather a reliable gas hazard indicator than a concentration measuring instrument. In applications handling a high risk of gas release (e.g. natural gas exploration) the information „gas is present“ is considered to be sufficient to activate safety relevant counter measures.

## 4 to 20 mA Transmitters

**A stand-alone sensor is not sufficient for gas detection. Sensor signals need to be electronically conditioned (some of them temperature-compensated), locally displayed (for calibration purposes), measuring ranges to be configured – and for all this power is necessary.**

It has become worldwide accepted that gas detection transmitters are operated by 24 V DC, and this voltage may vary within wide limits, e.g. between 16 and 30 volts. The transmitter's electronics convert the sensor signal into an output current so 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 transmitter and controller is cut, no current will flow (the current is 0 mA), and the controller will recognize this condition, activating a fault alarm. Moreover, signals lower than 3.8 mA or higher than 20.5 mA are not interpreted as a measuring signal but as special signals to indicate underrange (negative measuring values) or overrange, and also special maintenance signals. The 4 to 20 mA-signal is a worldwide accepted industry standard which, in opposite to voltage signals, does not depend on the cable resistance, which has low impedance (resistance) and is relatively immune to electromagnetic interferences

Transmitters with electrochemical sensors have such a low power consumption that they can be operated with even less than 4 mA, and can draw, depending on the gas concentration, an additional current of 4 to 20 mA from the power supply: Only two wires are needed for power supply and measuring signal. However, transmitters with catalytic bead sensors or infrared-sensors have higher power consumption and require 3 wires for power supply and signal.

The 4 to 20 mA signal can also be used to superpose a symmetrical frequency modulated signal of  $\pm 0.5$  mA to exchange additional digital information between controller and transmitter. This is the so-called HART signal, which can also be used to address certain transmitters by their digital addresses and poll their actual measuring signals and more. Several HART compatible transmitters can communicate on only one 2-core communication cable.

Digital communication, via HART or via the so-called RS 485 interface, enables the customer to remotely query the transmitters' "well-being" and preventively perform maintenance actions based on the results.

## **Sampling**

**There are many reasons not to have the sensor directly at the location where the target gas (gas to be measured) may occur. Instead of this continuous sampling can be performed which may also have advantages: The gas sample can be pre-conditioned (e.g. by filters), can be dried and tempered, condensate can be trapped, pressure changes can be compensated, and by means of solenoid valves further sampling paths can be activated. Especially test gas can be applied automatically to the sensor.**

### **Zone spreading**

When sampling from a hazardous area (mostly zone 1) the ex-zone is spread via the sampling tube into the safe area. Since in the safe area there are no means of explosion protection, ignition becomes possible. This can be avoided by using flame arrestors in the sampling tube. Flame arrestors do not inhibit the ignition, but prevent a flash-back into the hazardous area.

### **Sampling tubes**

The smaller the sampling tube's cross section, the higher the pressure drop – the greater the tube's cross-section, the longer the response time: 4 mm inner diameter and a flow of about 1 to 2 liter per minute is a good compromise. Pre-sampling Using a strong pump (10 to 20 L/min) gas sampling can be realized over longer distances (up to 100 to 150 m). A second small pump (approx. 1 L/min) should be used to supply the gas sample taken from the pre-sampling tube to the sensor.

### **Sampling line monitoring**

Considering the safety relevance it is essential to know that sampling basically increases the response time and that the complete sampling line needs to be monitored for proper function. This is mostly done by a flow meter with switch contacts which, in case of a blocked sampling tube or pump failure, trigger an alarm. If filters or condensate traps are used, they need to be maintained regularly.

### **Material and wall adsorption effects**

The tubing material should preferably be PTFE (Teflon), Viton, or stainless steel. Some gases tend to increased adsorption on the material's surfaces and this may influence the measuring signal especially for ppm-measurement.