Sensor Technology

FOR INDUSTRIAL SAFETY

GAS Detection

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New technologies come and go but the bulk of today's industrial safety gas detection equipment is based on tried and trusted methods. Although the methods are old, constant innovation is keeping track with users' demands for ever smaller and more sophisticated instruments. This is as true on the sensor front as it is in the software and instrument design.

Detection of a wide range of simple reactive gases such as Oxygen, Carbon Monoxide and Hydrogen Sulphide is possible using electrochemistry, which captures the electrons exchanged in a chemical reaction and allows them to be measured as an indication of the amount of gas present.

Non reactive gases such as methane can not be detected by this principle, however their combustible properties allow a simple detection system based on a heated bead to be used and this is known as the Pellistor or Catalytic bead.

Both of the above detection systems make use of the chemical reactivity of the gas, however the physical properties may also be used to provide the detection principle. Non Dispersive Infra Red detectors measure the absorption of Electro-magnetic radiation by the gas as it excites the vibrational resonances in the molecular structure. The wavelength of radiation used is chosen either to select a particular gas or to allow the detection of a board range of chemically similar gases, such as the aliphatic saturated hydrocarbons.

Turning these detection principles into a sensor suitable for the industrial safety market has been City Technologys forte for the last 25 years, and some of the latest innovations are described here as well as presenting the basic principles for each detection method

Electrochemistry

We are all surrounded by electrochemistry in our daily lives from the batteries in our cars and mobile phones to the tiny batteries that power hearing aids. And in the future perhaps even in Fuel Cells that may one day power our cars and provide the power to our homes. Indeed it was as a spin off of this work in the 1960's that the first of today's generation of Oxygen sensors was developed.

Oxygen Sensors

Fig. 1 shows a schematic of an electrochemical oxygen sensor. It comprises a Lead electrode which we traditionally call the Counter (or Anode in this case) and a special ptfe supported catalyst layer which can react with Oxygen called the Sensing Electrode (or cathode). Both of these electrodes are housed in a plastic body filled with a salt solution to act as an internal ionic conductor. The cathode electrode has a complicated role to play as it must allow gas to get to the catalyst from outside and also allow electrolyte to get to the catalyst but not to leak out through the gas access hole. This is achieved by using a thin (6 thou) porous ptfe tape as the supporting membrane. This material is very similar to 'plumbers tape' and is porous to air but can stop liquid from passing through.

In use Oxygen flows through the gas access hole or 'Diffusion Barrier' to the sensing electrode where the catalyst promotes the following reduction reaction to occur:

$$O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$$

The hydroxyl ions flow through the cell to the Lead anode where they react with the Lead, liberating electrons that are consumed at the cathode:

$$2Pb + 4OH^- \rightarrow 2PbO + 2H_2O + 4e^-$$

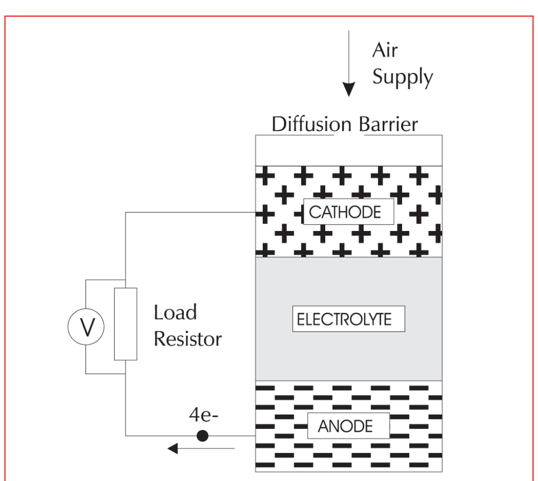

Fig. 1: Oxygen sensor schematic

As soon as a connection is made externally between the sensing and counter electrodes the current will start to flow and by measuring the current the flux of oxygen which is reaching the cathode may be determined.

The overall cell reaction is thus:

$$2Pb + O_2 \rightarrow 2PbO$$

The life of such a sensor is governed by the mass of lead inside and the rate at which it is used up. This in turn depends on the signal and the level of Oxygen in the atmosphere under test. As customers demand ever smaller sensors which therefore contain less lead the operating signals must be continually reduced if the target of a 2 year life is to be maintained

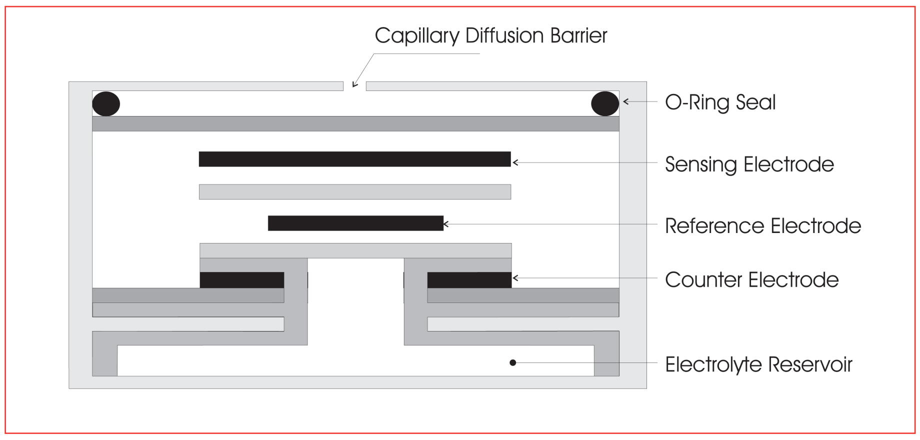

Fig. 2: Toxic sensor schematic

One further step is needed to turn this from an indicator into a quantitative sensor and that is to make the diffusion barrier sufficiently restrictive that it is the controlling factor in determining how much gas the sensor reacts with. By doing this we remove much of the variability of the underlying chemistry and the output of the sensor is then controlled by the physical characteristics of the diffusion barrier.

In practice there are two types of diffusion barrier in common use – capillary holes and solid membranes. Their properties are quite different and lead to very different sensor properties.

Sensors with capillary holes measure the volume % concentration of a gas whereas those with solid membranes respond to the gas partial pressure. These two measurements are related by the fact that the concentration is the partial pressure divided by the total pressure. Both measurands are valid with partial pressure being favoured in medical applications as it more closely relates to the way oxygen is absorbed in the lungs, whilst concentration has long been preferred in portable safety

Fig. 3: MICROceL™ vs 'standard' H2S Sensor

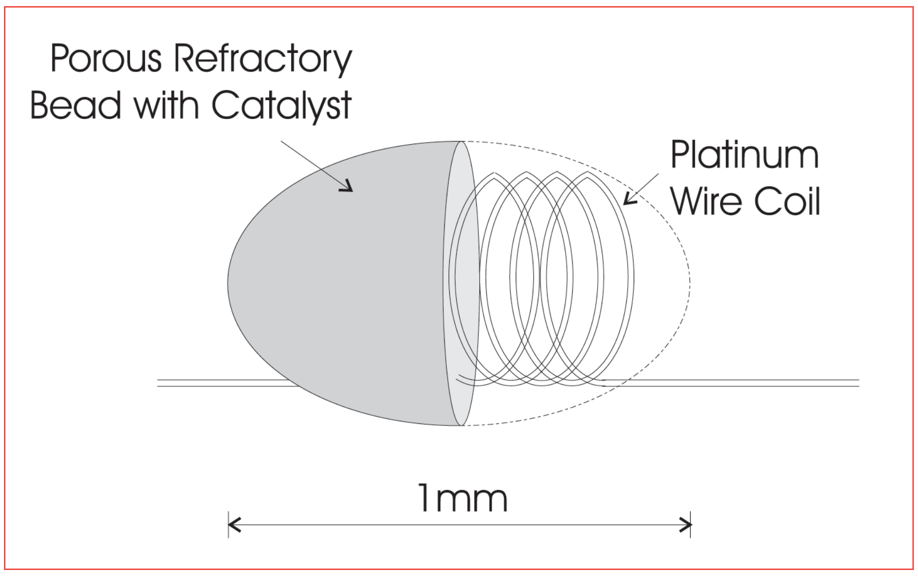

Fig. 4: Pellistor bead construction

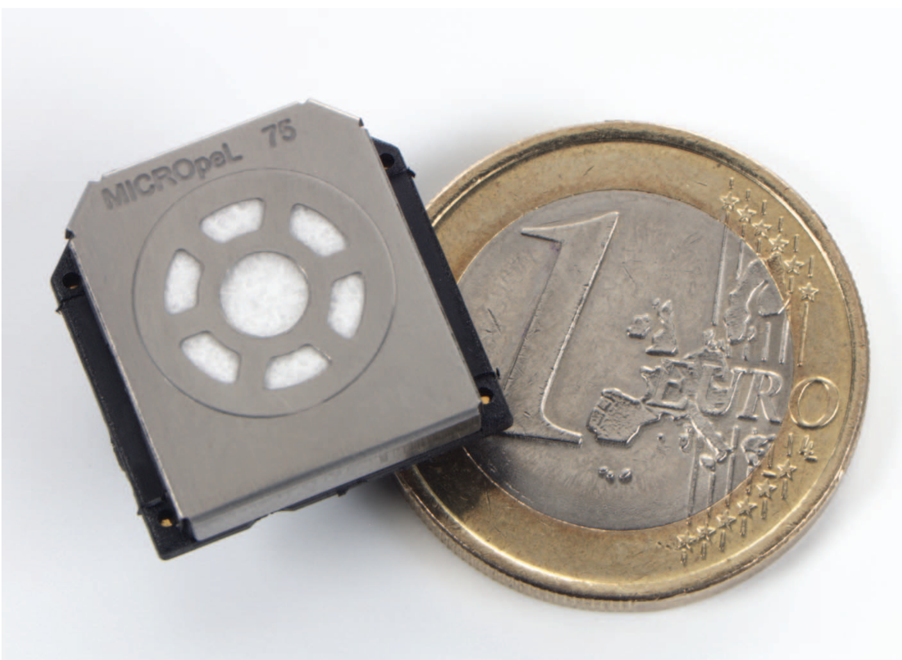

Fig. 5: MICROpeL™ miniature pellistor

units as is does not change during a shift as weather patterns cause atmospheric pressure to move up or down.

Capillary sensors also have the benefit of much lower temperature coefficients which are usually small enough to ignore, but suffer from transient signals when pressure is suddenly increased or decreased which must be carefully damped by the sensor designer and instrument manufacturer if false alarms are to be avoided.

Toxic Gas Sensors

Detecting gases such as CO, H_2S, SO_2, NO, NO_2, Cl_2, NH_3, HCN, HCl, PH_3 and some others can also be done electrochemically. What is needed is a catalytic electrode which can catalyse the oxidation or reduction of the gas in question. In general these catalysts are platinum group metals or alloys and the electrolyte is no longer a salt solution but a strong acid.

A typical example is H_2S which can be oxidised on a Platinum sensing electrode as follows:

$$H_2S + 4H_2O \rightarrow H_2SO_4 + 8H^+ + 8e^-$$

The counter will then need to undergo a reduction reaction to consume these electrons and would use atmospheric oxygen in a similar way to the oxygen sensor above, however in acid solution the reaction would then be:

$$2O_2 + 8H^+ + 8e^- \rightarrow 4H_2O$$

This would be a 2-electrode sensor, just like the Oxygen sensor above however in this case the performance might be restricted.

A better design would be to incorporate an extra reference electrode (fig. 2) to measure a stable internal potential and use this in a special operating circuit (potentiostat) to stabilise the operating potential of the sensing electrode. This is called a 3-electrode sensor and forms the bulk of the sensors used in safety instruments today.

Sensors based on these principles should last a long time as there is no consumption of any materials during the sensing process, however there will always be some degradation of the catalyst occurring over time and a typical life expectancy would be 3-5 years.

As with Oxygen sensors the trend is towards smaller sensors and the challenge for smaller sensors is to maintain sufficient electrolyte inside a very small housing to cope with use at extremes of humidity. Sensors with a Sulphuric acid electrolyte will tend to dry out when operated in very dry environments and to absorb water in very humid ones. Sufficient space must be left and sufficient electrolyte used to accommodate these swings. This means small sensors must have small signals to reduce the rate of water loss/gain and this is a considerable challenge.

The new MICROceL™ range of sensors from City Technology (fig. 3) shows how it is possible to maintain performance in a very small package size.

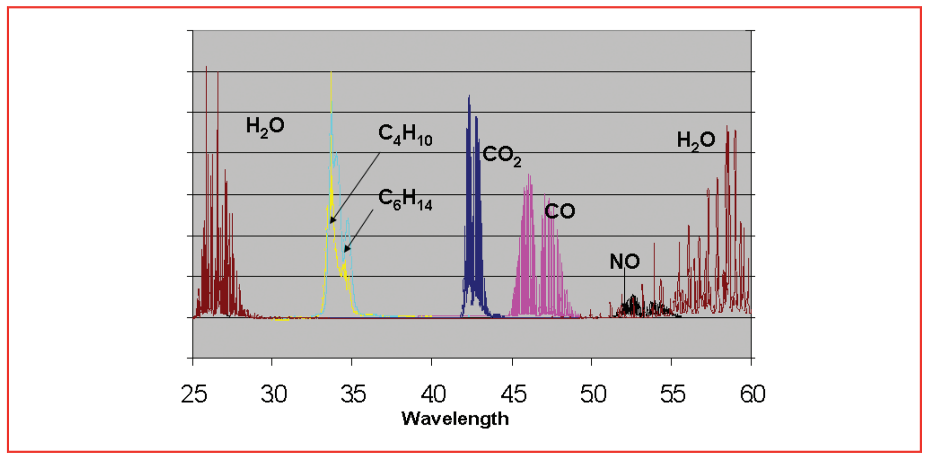

Fig. 6: Absorption spectra

Pellistors

Detection of a potential explosive atmosphere has traditionally made use of the Catalytic Bead or Pellistor sensor. This is essentially a platinum coil heated to 400-500°C and coated with a ceramic catalyst (fig. 4) designed to promote the combustion of any flammable gases present. The heat released from the combustion process causes the bead temperature to rise and the resistance to increase.

It is normal to operate the Pellistor as a pair of devices, one of which has been deliberately inactivated so it is not affected by the presence of the combustible gas, and to place them in a Wheatstone bridge circuit so that the small resistance changes may be measured.

Since the mode of operation is actually to try to burn any combustible gas present these devices are placed in a flameproof housing, behind a flame arrestor in order to be safe to use in a potentially hazardous atmosphere. They are normally supplied as matched pairs in an approved housing with all the necessary safety certifications.

Pellistors are a good match for the application because they measure the property of interest directly i.e. they respond to the combustible nature of the gas. The sensitivity to different gases varies, however when expressed relative to the LEL of the gas, many are quite similar. Thus it is possible to have a very general combustible hazard warning device for a wide range of gases. As always the manufacturers data sheets should be consulted to determine the sensitivity to any particular hazard relative to the calibration gas that has been used.

Pellistors have two main drawbacks – the power used and the potential for poisoning or inhibition by certain materials such as sulphur and silicon containing molecules. Manufacturers are constantly improving poison resistance and today's portable safety sensors are an order of magnitude less susceptible to poisoning than 10 years ago.

Power consumption is still an issue having decreased by only a factor of about 5 since the very first commercial use. Nevertheless clever packaging has reduced the size dramatically as the picture of the MICROpeL™ next to the Euro shows (fig. 5).

Infra-Red

Non Dispersive Infra Red detectors measure the absorption of infra red radiation over a frequency range. The spectra (fig. 6) shows some of the gases of interest and their absorption peaks

By choosing a single frequency it would be possible to uniquely identify many different compounds however current low cost systems use broad band sources and detectors with some form of wavelength filter to select the spectral region of interest. In this case it is possible to detect a range of similar compounds such as Butane /Propane/ Pentane although with differing sensitivity.

These sensors differ significantly from the Pellistors in that they are looking directly at the amount of a particular gas present and not at it's combustible nature. However because they are based on a physical property of the molecules they are not subject to poisoning and have the benefit of being fail safe against a number of fault conditions.

The technology is capable of being packaged into the industry standard 20 x 16mm cylinder size (fig. 7) and supplied as a safety approved device for use in potentially hazardous areas. Currently the power consumption is fairly high for a portable unit, but much work is ongoing to try to find useable solid state sources which would offer significantly lower power systems.

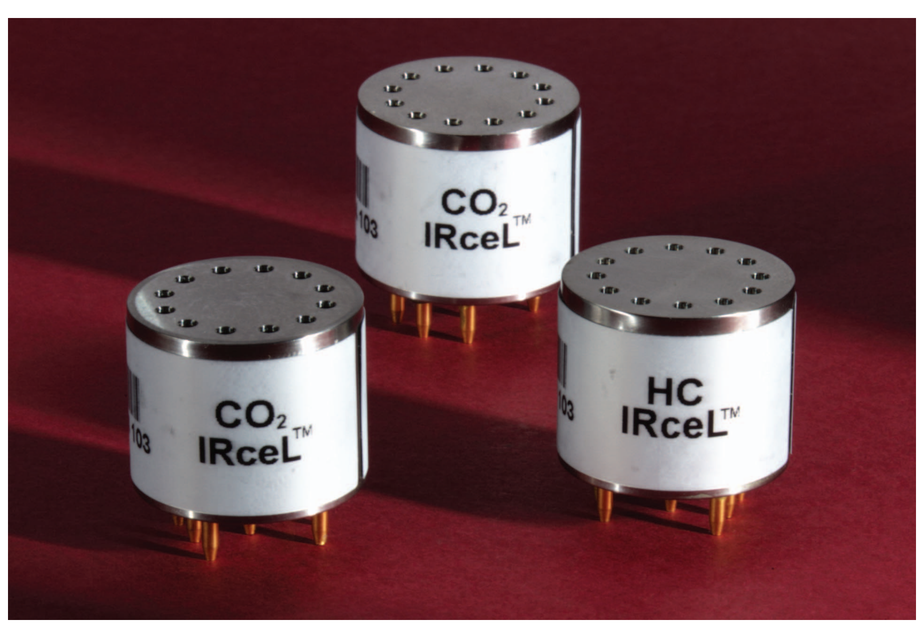

Fig. 7: IRceL™ miniature NDIR gas sensors