Thermo-paramagnetic analysers reduce the cost of oxygen analysis in reactor applications

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In this article Jason Byrne, Product Manager, Michell Instruments considers the challenges of oxygen monitoring in reactor processes and compares some of the oxygen sensors that can be applied to this safety critical application.

Pharmaceuticals and specialty chemicals are typically produced in batches by mixing several components in a reactor. These reactors vary in size from table top glass jars to large stainless steel or glass lined vessels with a mixer (like a large scale domestic food blender).

The ingredients within the reactor are often highly corrosive chlorinated compounds which, when mixed with solvents, can result in the void between the top of the reactor and the liquid level being filled with highly inflammable vapours.

When combined with oxygen and a potential source of ignition (such as a static discharge, a spark generated by metal-on metal contact or hot spots due to friction or mechanical wear) there can be a risk of explosion.

One way of ensuring that the mixture of air and solvent vapours stays below flammable levels is to use a nitrogen purge. In the past, operators would permanently feed nitrogen to the process and not worry about the oxygen level. However, nitrogen is a consumable with an associated cost and its use should be limited.

By accurately monitoring the oxygen level in the reactor, the nitrogen feed can be shut down when the O_2 level is below the level specified for the site (for example 5% Oxygen). This level will be a safe point below the Minimum Oxygen Concentration (MOC). By ensuring that the MOC is not exceeded, operational costs are reduced while ensuring that safe operation is maintained.

Choosing the right technology

There are several technologies available for measuring oxygen in reactor applications with each having its individual characteristics. Most reactor applications demand reliability and have specific requirements in terms of accuracy, ± 0.5% O_2 being a typical figure. The composition of the gas being measured is also a

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consideration since the gas condition and the presence of any contaminants, can significantly affect sensor life and accuracy. Other factors include the initial purchase cost and the total cost of ownership taking into account any maintenance requirements.

Electrochemical cell

The traditional choice of oxygen sensor for reactor applications is the electrochemical cell. Advances in design and manufacturing, together with refinements in electrode materials and enhanced electrolyte formulations, have extended the life and response times over earlier versions. However, the electrochemical reaction inherent in their design limits the life of these sensors with a replacement sensor being typically required after every 6 to 12 months of service. A further limitation is their susceptibility to damage when used with samples containing acid gas such as hydrogen sulphide, hydrogen chloride, sulphur dioxide, etc.

So while these instruments have a relatively low purchase price, their lifespan is limited. They rely on a program of cell replacement being in place to ensure cells are changed before their performance degrades. Expired cells can give inaccurate readings that could lead to a dangerous situation and for this reason they are not the best choice for safety critical applications. Whilst they may appear to be a low cost option, the regular maintenance costs add up over time. As a result, electrochemical cells can be an expensive option when the total cost of ownership is taken into account.

Thermo-paramagnetic sensors

A better option for many applications is the use of sensor cells based on thermo-paramagnetic sensor technology. Oxygen is a paramagnetic gas, which means that it is attracted by a magnetic field. This magnetic susceptibility is much greater than most other gas molecules and therefore this physical property is ideal for the determination of the level of oxygen in a wide range of background gases.

As this technology relies solely upon fluctuations in gas flow due to a magnetic field and not internal moving parts, the sensor will operate efficiently under a wide range of environmental conditions. This insensitivity to mechanical shock makes the sensors suitable for installation where vibration or movement could pose a problem for other sensor types.

In general, paramagnetic oxygen sensors offer very good response time characteristics and use no consumable parts. They also offer excellent accuracy over a range of 0-1% to 25% oxygen.

With regard to sensor life, the thermo-paramagnetic sensors used in the latest generation instruments such as the Michell Instruments XTP601, will last the life of the instrument in normal operation. These instruments feature enhancements such as an integrated touch-screen display that makes configuration and calibration easier, reducing time spent and further reducing the total cost of ownership.

The XTP601 has a very low drift and with no moving parts, maintenance is minimized. While the initial purchase price is slightly higher than sensors based on electrochemical cell technology, life cycle costs are much lower. This makes sensors based on paramagnetic technology a popular choice for oxygen monitoring in reactors.

Magneto-dynamic paramagnetic (MDPM) sensors

Magneto-dynamic paramagnetic (MDPM) sensors are one of the most expensive choices. They offer similar calibration intervals to thermo-paramagnetic sensors, but with the benefit of faster response times. However, they are prone to damage by liquid, particle ingress or by pressure shocks.

Most magneto-dynamic sensors consist of a cylindrical shaped container, inside of which is placed a small glass dumbbell. When a sample gas containing oxygen is processed through the sensor, this results in the dumbbell rotating. A precision optical system consisting of a light source, photodiode, and amplifier circuit is used to measure the degree of rotation of the dumbbell.

In some paramagnetic oxygen sensor designs, a restoring current is applied to maintain the dumbbell in its normal position. The current required to maintain the dumbbell in its normal state is directly proportional to the partial pressure of oxygen and is represented electronically in per-cent oxygen.

As well as being an expensive option, the design of the magneto-dynamic sensor is quite delicate and the sensors are not recommended for applications where they will be exposed to movement or vibration.

Summary

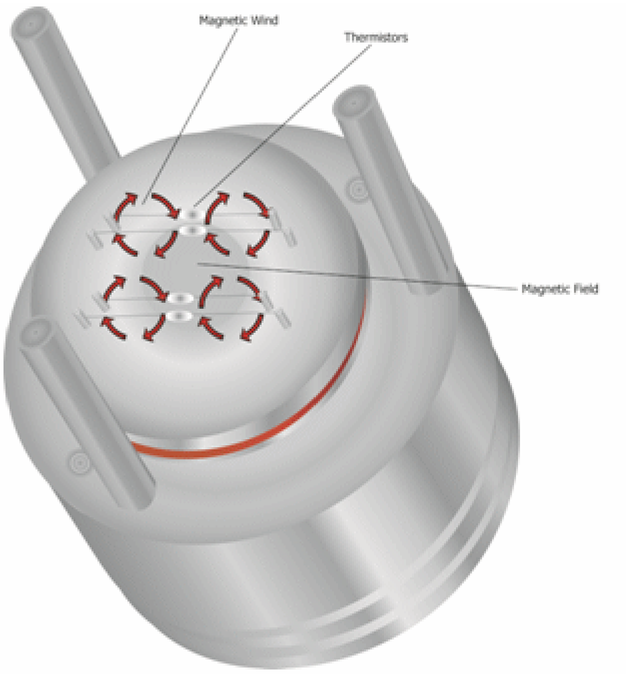
Accurate and reliable oxygen monitoring in reactor vessels is essential to minimize the risk of a build-up of an explosive mixture of gases. While sensors based on electrochemical cell technology are the lowest cost option, their limited operating life makes them unsuitable for many safety related applications. High maintenance costs make them an expensive option when the total cost-of-ownership is taken into account.

Magneto-dynamic paramagnetic (MDPM) sensors are the most expensive option typically being around one and a half times the cost of a good thermo-paramagnetic oxygen analyser. Whilst they offer high accuracy and fast response times, these may exceed the requirements for many reactor applications. Their delicate construction means that they are not suitable for applications where movement or vibration is present. In addition, they are very prone to damage by liquid, particle ingress or by pressure shocks.

For most batch reactor applications the best option will be a paramagnetic oxygen sensor such as the Michell Instruments XTP601. Whilst the initial purchase price is more than electrochemical cell sensors, their low maintenance requirements means this translates into an excellent balance of accuracy, reliability and total cost of ownership. For example, based on a modest premium compared to an electrochemical sensor, the savings achieved by the reduced maintenance costs would mean that this additional investment would be recovered within two years.

Thermo-paramagnetic oxygen analysers - How they work

Thermo-paramagnetic oxygen analysers like the Michell XTP601, use a combination of paramagnetic and thermal conductivity technology to accurately measure oxygen. The analyser works on the principle that the magnetic susceptibility of oxygen decreases inversely with its temperature. This effect causes a flow of gas containing oxygen inside its temperature-controlled measuring chamber. The flow or "magnetic wind" alters the equilibrium temperature between thermistor pairs. This results in a change of the electrical resistance of the sensors and a signal that is proportional to the oxygen concentration in the measured gas.



The advantages of thermo-paramagnetic technology include its outstanding stability and insensitivity to mechanical shock. This means the sensor will operate efficiently under a wide range of environmental conditions. Analysers like the Michell XTP601 are suitable for installations where vibration or movement could pose a problem for other sensor types.