MONITORING OXYGEN IN COKE OVEN OFF-GAS FOR SAFE OPERATION OF A COKE OVEN[01]

Todd Newell[02]
Ian Mackay[03]
Sergio L.C. Ferreira[04]

SUMMARY

The off-gas produced in a Coke Oven is highly rich in Hydrogen and is therefore extremely flammable in the presence of low levels of Oxygen. The gas also contains large quantities of particulate, tar and sulfur, which makes is difficult to get a clean dry sample to an Oxygen Analyzer.

The purpose of this paper is to demonstrate how a carefully designed Oxygen Analysis System can provide a reliable and fast response measurement on this difficult but critical measurement. The fast response of the system is of utmost importance to the safety of the plant in order to avoid potential explosion risks caused by the presence of Oxygen in the Coke Oven off-gas. The reliability of continually delivering a clean dry sample to the analyzer means more time on-line and less downtime maintaining the system.

Key words: oxygen, safety, coke oven

---

(01) Paper presented at the "I Seminario Internacional sobre Reducao", Belo Horizonte, MG, Brasil, 24-26 September 2001
(02) Servomex Company, Inc., Norwood USA, Latin American Regional Manager
(03) Servomex Company Inc., Norwood USA, Director of Sales
(04) ENGEZER Comercial Ltda., Rio de Janeiro, Director

THE APPLICATION

Carefully blended coal is charged into coke oven batteries. The coal is heated and pyrolysed in the ovens until it becomes coke. During this process a highly flammable hydrocarbon rich off-gas is produced. This gas is refined and used as fuel for process heaters and other combustion processes throughout the Steel Plant.

Due to the high flammability of this gas, the quantity of oxygen in the gas must be carefully monitored in order to assure that there is less than 1% O2 as in the presence of an ignition source, only a small concentration of O2 could lead to an explosion. The response time for the analyzer is key to advising plant operator of a dangerous situation so that the appropriate action can be taken to avoid potential disaster.

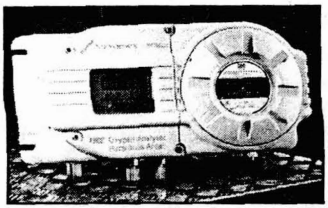
Coke Oven off-gas is hot, wet and dirty and contains high concentrations of tar and sulfur, which poses a challenge to the delivery of a clean dry sample, required by the analyzer.

THE ANALYZER

The Oxygen analyzer for this application is a highly critical component to the monitoring system. The analyzer must be a highly reliable device with a fast response. The analyzer must also be able to accurately measure oxygen in a stream of Hydrogen, Methane, Carbon Monoxide, among other gases with no interference from these background gases. Since the sample is rich in hydrocarbons, the analyzer should also be FM or CSA approved to handle flammable samples in a Class I, Division 1, Group B Area. The device should also be easy to maintain and calibrate in a hazardous area without the need for "hot works" permit.

In order to integrate the analyzer into an overall safety protection system, the analyzer should have a 4-20mA output signal and alarm contacts to indicate high Oxygen concentration. One of these alarm contacts can be set as a warning alarm which indicates a higher than normal concentration of Oxygen in the gas. The second can be set to shutdown the process and purge the line with an inert gas to eliminate any presence of Oxygen in the coke oven off-gas. The 4-20mA analog output integrated into the plant's Distributed Control System (DCS) or a Programmable Logic Controller (PLC) can also be used to initiate alarm warnings and shutdowns.

As the environment in a Coking Plant is aggressive with high levels of dust in the air, a NEMA 4 or 4X enclosure is essential to protecting the analyzers sensing device and providing for continuos, reliable operation and maximum "up-time" for the monitoring system.



Xendos 1900B Oxygen Analyzer

THE SENSING DEVICE

As stated above, the Oxygen analyzer must be reliable, with a sensing device that is immune from interference from background gases and provide a fast response. In addition, the sensing device should require minimal maintenance so as to maximize the time the analyzer is operating on line and provide a stable reading. The ideal measurement technique for this difficult application is a magneto-dynamic paramagnetic measuring cell.

Oxygen has a unique property when compared to other gases; it is attracted to a magnetic field whereas the majority of other gases reject a magnetic field. This unique property makes the paramagnetic sensor the most appropriate solution for measuring Oxygen in a background stream of hydrocarbons as the Oxygen measurement will not be effected by the presence of other gases.

The magneto dynamic paramagnetic transducer is composed of the following key components:

- Non –uniform magnetic field produced by vertically mounted permanent magnets
- Two Nitrogen filled spheres on a flexible suspension with a mirror
- A feedback coil which surrounds the spheres
- An LED light source which continuously reflects off of the mirror on the suspension
- Photocell sensor which detects the change in angle of the reflected light source and sends an output to the feedback coil

When a clean, dry gas sample from the coke oven off gas process line enters the measuring cell, the oxygen molecules are attracted to the center of the non-uniform magnetic field while the other gases in the sample reject the field. The Oxygen molecules deflect the sphere out of the magnetic field (the zero or null position) and a change in the angle of the LED light reflected off of the mirror is detected by the photocell sensor. The photocell sensor immediately sends an output signal to the feedback coil to "balance" the spheres thus returning them to the null position. The signal produced by the photocell sensor is directly proportional to the quantity of oxygen in the sample.

As the sensing device continuously seeks the null position, the photocell produces a constant signal to the feedback coil thus providing continuos updates as to the

quantity of Oxygen in the sample. As long as the sample is flowing through the system, a response time of less the 4 seconds from measurement at the analyzer to the 4-20mA analog output is expected. The measuring cell itself is heated to a nominal temperature of 60°C in order to eliminate the effect of varying sample temperatures on the measurement. Both the sample and calibration gases enter the cell at the same temperature, which provides for a stable and consistent Oxygen measurement.

An additional benefit to this type of sensing device is its ability to be integrated into an analyzer that can indicate when the sensor has failed. When there is a problem with the sensing device, such as a broken or damaged suspension, due to the presence of particulate or water (normally caused by a failure in the sample conditioning system), the signal sent by the photocell detector can never return the spheres to the null position. The analyzer's electronics detect the instability of the feedback signal and immediately "jams" the 4-20mA output to 0mA thus advising the operator in the control room that he or she is now operating without an analyzer.

Furthermore, this magneto dynamic paramagnetic sensor requires no programmed replacement and only a recommended quarterly calibration. The calibration is easily done using oxygen free Nitrogen for the ZERO and instrument grade air for the SPAN calibrations.

When compared to electrochemical sensors one can see clear-cut advantages:

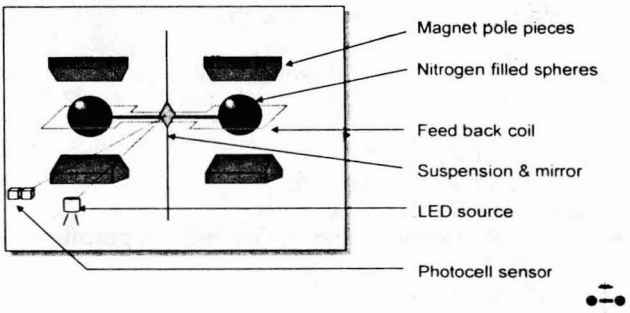
- No need for planned replacement
- No need for frequent calibration to test if the sensor is working
- No worry of a sensor failing without advice
- No problems of sensor contamination caused by corrosive sample
- Overall lower operating cost with more on-line operating time.

When compared to other types of paramagnetic sensors, different advantages should be noted:

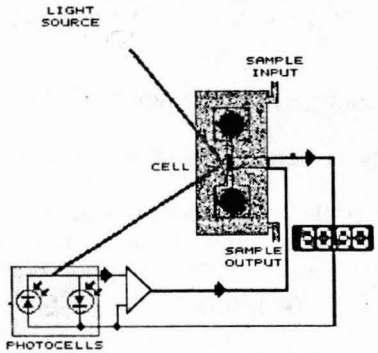
- No need for constantly flowing reference gases
- No affect caused by varying thermal conductivity constants in background gases

Servomex

Servomex Paramagnetic Cell



Null Position of Paramagnetic Cell



Magneto-Dynamic Paramagnetic Oxygen Transducer

THE SAMPLE CONDITIONING SYSTEM

The major challenge in continuously monitoring oxygen in coke oven off gas is delivering a clean dry sample to the Oxygen analyzer. If the sample system is not correctly designed, the analyzer itself can be damaged due to the presence of particulate or liquids, which destroy gas sensors of any type. In order to maximize the "up-time" of the system, a well designed and maintained system is essential.

A typical Oxygen analyzer requires the following sample gas conditions at the inlet of the instrument:

Sample Inlet Pressure:	0.04 psig
Sample Inlet Flow:	50 –250 ml/minute
Sample Vent Pressure:	11.5 to 18 psia
Sample Dew Point:	Non-condensing at ambient temperature
Sample Temperature:	-10 to 50°C
Sample Particulate Size:	< 3 microns
Sample Condition:	Clean and free from oil and condensate

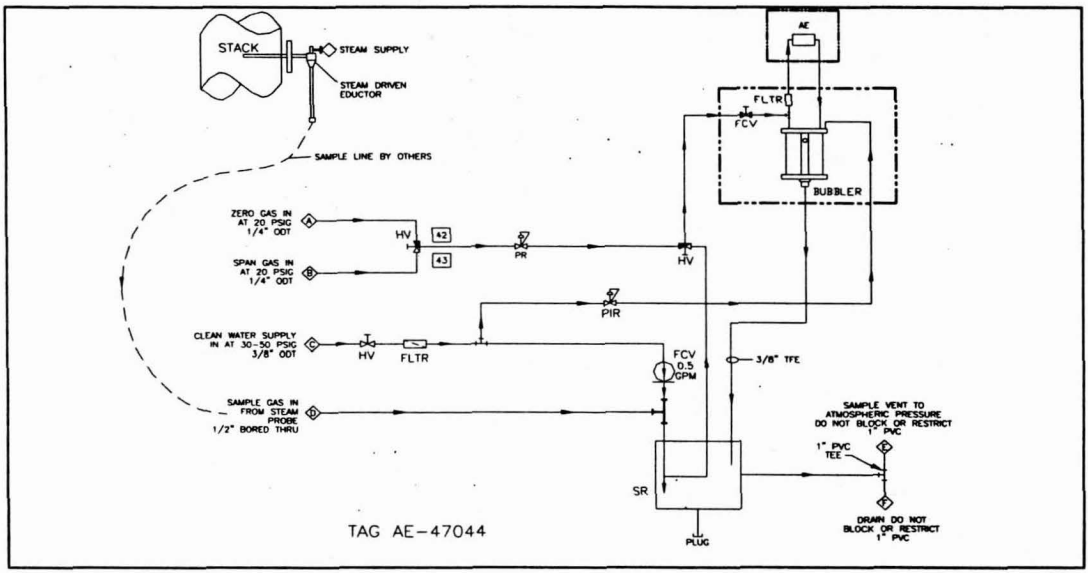
The sample conditioning system must take a sample from the process, which is dirty with potentially high levels of sulfur, and deliver it to the analyzer in the above conditions. In most cases, the sample conditioning system begins just before the analyzer inlet and the sample is simply taken from the process by a simple hollow probe tube and a 3/8" diameter stainless steel sample line. In the case of the system for the coke oven gas analytical system, the conditioning begins at the sample take-off point

The system consists of the following key components:

- A Stainless Steel, Hastelloy or ceramic sample probe which is inserted into the process
- A steam powered aspirator or ejector to draw the sample from the process
- A 316 Stainless Steel or Hastelloy sample line or acid resistant steam hose to transport the sample from the process to the analyzer
- A Water Wash Separator with drain to remove corrosive condensed gases and particulate from the sample and separate the gaseous sample from the liquid
- A Wet Gas Bubbler that regulates the flow of the sample to the analyzer by the use of two dip tubes of different lengths inserted into a bowl of water. The difference in tube lengths and the constant flow of bubbles produced by sample passing through each tube indicates that the required sample flow is getting to the analyzer.

Dry steam is supplied through the aspirator to the sample probe and then ejected through a jet situated in the mouth of the aspirator venturi. The flow of steam causes the sample gas to be drawn into the probe. The stream and sample gas pass out of the probe and down to the sample line to the water Wash Separator at a positive pressure. The flow of steam through the sample line prevents the build up of any corrosive condensates and particulate and assures there is no clogging of the sample line.

The sample then passes through the Water Wash Separator, which is continuously, supplied with potable water. The water dilutes any sulfur in the sample and removes any particulate in the sample. The sample contaminants are drained from the separator and the clean sample passes to the analyzer. Any water droplets that the sample may still contain are filtered out and the droplets drain into the Wet Gas Bubbler. Once the sample passed through the paramagnetic measuring cell and the oxygen is measured, it exits the sample system through the Wet Gas Bubbler, which produces bubbles indicating that sample is flowing through the analyzer. The Wet Gas Bubbler serves as an attractive alternative versus a standard rotameter when wet gas samples are being handled. The presence of any humidity in a rotameter designed to measure gaseous flow would damage the rotameter and result in additional required maintenance on the system. By using the two dip tubes of different lengths, the sample flow is controlled without worrying about water droplets damaging the flowmeter.



Flow Diagram of Typical Coke Oven Off-Gas Monitoring System

UTILITIES REQUIRED FOR SYSTEM

The following utilities are required for the successful operation of the Coke Oven Off-Gas Monitoring system:

- Instrument Grade Air as per ISA standard S 7.3 for the SPAN calibration of the oxygen analyzer
- 99.99% oxygen free nitrogen for the ZERO calibration of the oxygen analyzer
- 117V or 220V Power supply for Oxygen Analyzer
- De-saturated steam at 50 psig for steam aspirated probe
- Potable water at 35 to 90° F or process water with a pH of 6 to 9 which is free of ammonia and particulate matter that could clog a 40 MESH strainer. This water is used for the Water Wash Separator.

CONCLUSION

The ability to safely run a process while minimizing maintenance and downtime are important to controlling operating costs of any plant. There are more than 30 Coke Oven Off-Gas Oxygen Monitoring Systems successfully installed worldwide thus insuring any plant operator that the proven design as described above will help to provide safe, long-term operation while minimizing costs associated with maintenance and downtime.