

White Paper

Using Flue Gas Oxygen Analysis to Improve Efficiency and Reduce Emissions in Complex Combustion Processes



Background

Whether for fired heaters burning natural gas, or rotary kilns with mixed fuels for cement or other manufacturing processes, Emerson's O₂ analyzers provide critical data for effective control and optimization.

Where there's smoke, there's inefficient combustion

These days, such should not be the case because there are technologies available that help optimize fuel and air mixing to ensure efficiency while minimizing emissions, regardless fuel type.

This is more complicated than it sounds because there is often only a small window of operating conditions where fuel efficiency and emissions are optimized (Figure 1). So how does a seemingly simple process with only two variables, fuel and air, get so complicated, and how do operators determine how to control it? When dealing with industrial-scale combustion processes, the only practical analysis method is looking at the chemical composition of flue gas coming out the stack. This is not new as a concept, but methods are evolving.

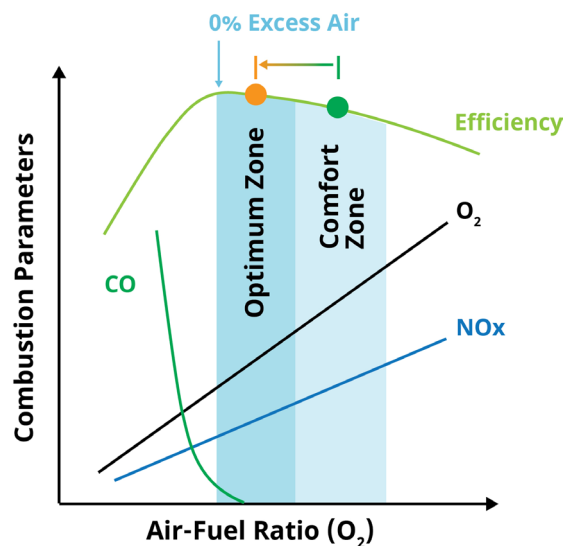


Figure 1. Any combustion process must have enough air available to fully combust all the fuel, but with a bit extra to cover for unavoidable inefficiencies. Determining where efficiency is highest and emissions lowest may be different in each case, but it always requires an effective O₂ sensor.

Virtually any industrial-size combustion process has some kind of sensor in the process to monitor oxygen (O₂) levels. Ideally, the amount of air drawn or forced into the firebox should not exceed that which is necessary to support full combustion of the fuel. Any air beyond that level reduces overall efficiency since the heat generated simply warms excess air rather than being transferred to the process.

The question is how closely air and fuel levels can match their ideal parameters since no combustion process is perfect. Some fuel always remains unburned, or it is partially unburned in the form of carbon monoxide (CO). Consequently, it is better to have slightly more air than necessary (lean fuel conditions) rather than too little air (rich fuel conditions). Some sophisticated

applications extend their O₂ analysis by looking at the fuel flow rate and calculating the theoretical amount of air necessary for perfect combustion, also known as the stoichiometric rate. For a natural gas fired unit, operators usually try to keep excess air between 5% to 10% to compensate for areas in the firebox where there might be inadequate fuel and air mixing.

Two different approaches

The question becomes, how much extra O₂ going out the stack should have been consumed with the unburned fuel within the stoichiometric rate, against how much is truly beyond the stoichiometric rate. Making this determination depends on what technology is used to monitor O₂ in the stack. Some techniques just measure total O₂ levels, while a zirconia sensor cell measures excess O₂ in the flue gas, a better approach for most applications.

A zirconia sensor cell (Figure 2) is placed on a probe extending into a duct in the flue-gas stream. Gases in the duct diffuse across the filter media into the diffusion chamber based on gas partial pressure equalization mechanisms. The gases then diffuse through the neck of the O₂ cell, which is packed with platinum coated beads, which protect the O₂ cell from poisoning and extend cell service life. The entire cell is embedded in a heater to maintain the zirconia disk at 390° F (736° C).

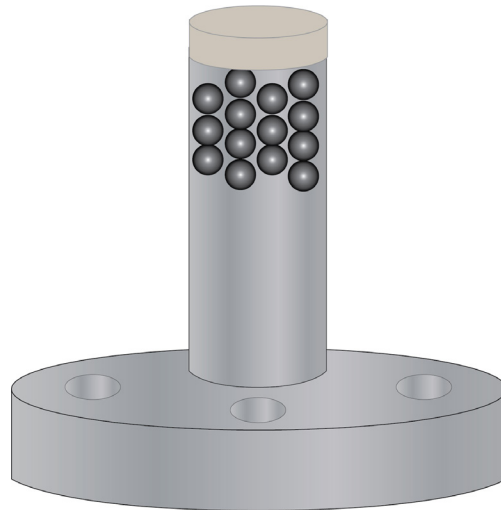


Figure 2. A zirconia sensor uses platinum coated beads to catalytically combust excess fuel, providing a true continuous measurement of excess O₂ from any combustion process.

If a sensor is just measuring total O₂ content in flue gas, the reading shows an undifferentiated mix of left-over stoichiometric O₂ and excess O₂. If operators misinterpret the total O₂ content as excess O₂ and act on that belief, they can drive the fuel mix even richer, making the problem worse, increasing the amount of unburned fuel and reducing efficiency.

A zirconia sensor has a particular characteristic to avoid this problem. Gas flowing into the sensor includes both O₂ and any unburned fuel. Given the high temperature and extensive surface area of the platinum beads, combustion of any remaining fuel traces is completed through catalytic

oxidation, so as the fuel is consumed, so is the stoichiometric O₂ with it. Since all combustion is completed, any O₂ still measurable represents excess O₂ rather than total O₂. Operators can thus confidently use this measurement to control air flow in real-time to maintain the percentage of excess O₂ they consider desirable.

Emerson's zirconia O₂ sensors

Since stack gas monitoring uses an in-situ sensor rather than a sampling system and remote analyzer, the sensor is exposed to high temperatures and particulates—and to potentially corrosive acid gases depending on the fuels involved. In years past, this often resulted in relatively short service life for the probes, made worse by complex mounting mechanisms

Emerson has worked over the years to develop this technology to make it more effective and reduce the maintenance drawbacks. The Rosemount Oxymitter and the Rosemount 6888A In Situ Oxygen Analyzer have become industry standards for many years, replacing troublesome older competitive units to improve combustion control, thereby improving efficiency and simplifying maintenance.

Now a new version is available with the release of the Rosemount CX2100 In Situ Oxygen Analyzer (Figure 3), designed to extend those benefits even farther with a range of operational improvements, plus lower cost of ownership over the unit's service life. There are many changes designed to improve operation, but most concentrate on reducing the lifetime cost of ownership, a large portion of which relates to maintenance, particularly in dirty and corrosive environments.



Figure 3. Emerson's new Rosemount CX2100 In Situ Oxygen Analyzer incorporates many features designed to extend sensor life and reduce maintenance intensity.

All combustion monitoring applications are challenging, but some are far worse than others. A basic natural gas-fueled boiler or fired heater is the simpler end of the spectrum, but even these processes subject the O₂ probe to high temperatures, and possibly acid gases resulting from sulfur contaminants and formation of NO_x compounds. Some of the harshest applications relate to coal-fired utility boilers, rotary kilns, and acid regeneration in the metals and mining segments. More on these in a moment.

Whatever the application, since O₂ sensors may be part of boiler control systems or environmental monitoring systems, they must be calibrated at specific intervals, and sensor cells have specific lifespans. If an O₂ sensor fails, continued operation without it could drift into process inefficiency, increase emissions, and eventually draw fines from local regulatory agencies. Replacing the sensor means withdrawing the supporting probe, opening the flue gas duct to atmosphere, typically drawing in air due to an induced draft. Over a longer period, the probe itself supporting the sensor may also need replacement due to corrosion.

Understanding improvements

Given this range of obstacles, let's look at how the Rosemount CX2100 In-Situ Oxygen Analyzer has upgraded features to improve performance and reduce maintenance requirements.

First, the transmitter/analyzer sections have been improved:

- The Rosemount CX2100 features a new capacitive-touch local operator interface, with easy-to-navigate menus that can be translated into seven languages.
- The transmitter can be mounted remotely from the probe, allowing personnel to access the analyzer, while staying out of unsafe process conditions.
- The transmitter is approved for hazardous locations and is backwards compatible with many legacy in-situ O₂ analyzers.
- The Calibration Check feature examines current calibration constants to ensure they are within specified ranges. This approach satisfies permitting requirements, and it can be carried out from the control room at any desired interval, without the need for technicians to access the equipment directly. Calibration or calibration checks can be run automatically with the optional SPS4001B Autocalibration accessory.
- The Flame Safety Interlock feature can be tied to a safety instrumented function capable of shutting down the system if the sensor recognizes a sudden change in O₂ level caused by a flameout, which would flood the system with unburned fuel, creating a potentially explosive mixture.
- The Rosemount CX2100 provides reliable data with excellent repeatability and drift specifications to ensure accurate O₂ measurements.

Second, probe mounting methods are more robust:

- The Quick Connect feature allows the probe body to be quickly replaced without disconnecting the electronics wiring. This new design feature increases uptime and minimizes maintenance time.
- The mounting flange has been reconfigured to reduce leakage potential, and it can use an existing mount. This avoids toxic flue gases escaping, while minimizing air infiltration for induced draft systems.
- The Abrasive Shield accessory is available for high particulate processes to protect and extend the lifetime of the probe.
- The Bypass assembly accessory is available for high temperature applications. The Bypass assembly extends the probe further outside the process, allowing flue gas to fill the Bypass assembly and cool slightly. The cooler flue gas may then be measured by the analyzer.
- The Probe Mounting Jacket option helps protect the probe when installed in high-temperature and dirty applications, such as kilns (Figure 5). Using a protective metal jacket lined with refractory insulation, the probe is shielded from extreme heat and abrasive particulates, while exposing just the sensor itself to the process. This extends probe life, and it may allow the use of less costly alloys. Where heavy dust loading can foul the sensor itself, air nozzles can be incorporated into the jacket to clear the sensor continuously or at intervals. The probe itself can still use the Quick Connect feature, so the jacket does not impede any required maintenance.

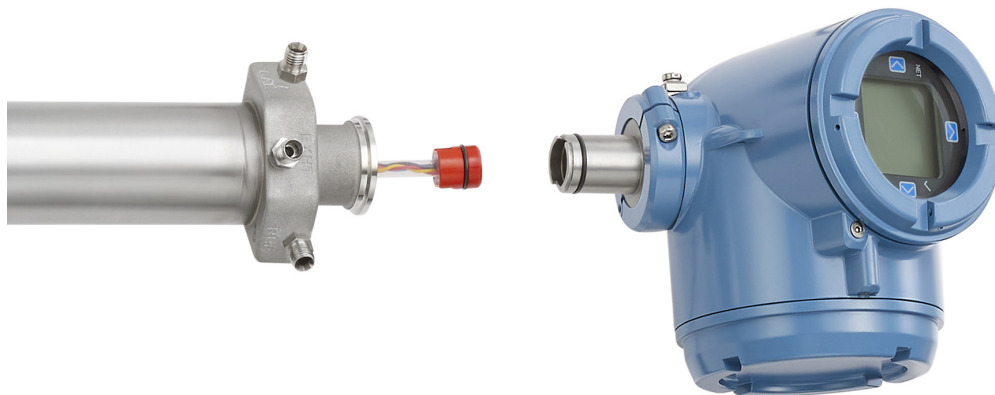


Figure 4. The Quick Connect feature allows users to remove and replace the transmitter without rewiring the probe body.

Third, the sensor assembly has new options:

- Cells are easily replaceable by unscrewing the shield. This makes changes possible with minimum maintenance and outage time.
- New standard sensor alloys are more resistant to corrosion from moderate levels of sulfur

compounds, and where levels are excessive, high-sulfur cells are even more durable, increasing service life.

- Diffusers are now available in a wider range of materials for different applications operating at various temperature ranges, including Hastelloy and ceramic offerings. A vee deflector accessory can be added to the diffuser for high particulate applications.
- Extended Temperature Option can handle continuous temperatures up to 1500° F (825° C) for extreme applications.
- The Plugged Diffuser option alerts when the diffuser needs to be replaced or cleaned after becoming plugged by particulates and debris.
- The Stoichiometer option detects when O₂ levels enter sub-stoichiometric (reducing) conditions.

Taking on the toughest applications

Within the world of combustion applications, some of the largest and most challenging are full-sized coal-fired utility boilers, and the massive rotary kilns (Figure 6) used in cement and lime production.

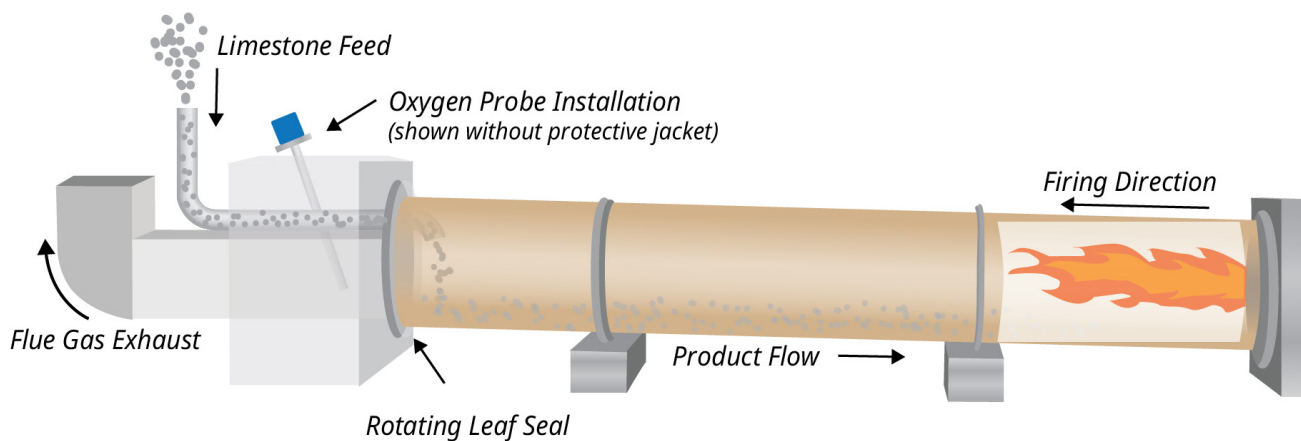


Figure 5. Rotary kilns are some of the toughest applications with high temperatures, high dust loading, and corrosive gases. The Rosemount CX2100 In-Situ Oxygen Analyzer is designed to take on these difficult environments, while still delivering minimal required maintenance and low operational costs.

Challenges include:

- Wide fuel variability as most kilns burn coal or pet coke, but may also add tires or combustible liquid waste, so flue gas composition can change drastically, affecting corrosiveness.
- High particulate loading in the gas stream, including dust from cement and lime, along with fly ash from coal, can clog sensor diffusers.

- Probes are usually inserted ahead of a baghouse, precipitator, or scrubber, so probes see flue gas at its dirtiest.
- High temperatures are possible depending on where the O₂ probe is placed. The exit of a lime kiln can easily be 1300° F (700° C).
- Large ducts may not have thoroughly mixed flue gas streams, so multiple probes may be necessary to average compositional stratification.

The Rosemount CX2100 is designed to handle all these and other challenges, but it is not reserved simply for difficult applications. In any situation, its capabilities deliver high reliability and low cost of ownership, regardless of where it's used. There are many configuration options so it can be tailored to fit specific requirements from basic to extreme, delivering a cost-effective package with ongoing payback over its full service life.

While reduced maintenance costs are substantial, the largest payback will be increased fuel efficiency combined with uninterrupted production, increasing overall output at lower cost for whatever unit where it is installed.

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