Pressure Compensated Oxygen Probes Explained

What are pressure compensated O_2 probes? Do I need pressure compensation for my application?

To answer these questions, we need to look at how zirconia-based oxygen probes make the measurement.

How Zirconia Cells Work

The zirconia cell is heated to 750°C and exposed to the process gas on one side and a reference gas (usually clean/dry air) with a known O_2 concentration on the other side. If there is a difference in O_2 concentration between the process gas and reference gas, the cell will generate a voltage (mV). The more significant the difference, the bigger the voltage developed. The analyzer measures this voltage and calculates the O_2 concentration.

The “force” that causes this voltage is the difference in partial pressure of oxygen between the process gas and reference gas. Partial pressure can be defined as the mole fraction (% concentration) times the total absolute pressure.

For Example:

Air at atmospheric pressure (407.1 inches water column (WC) absolute pressure) has an oxygen concentration of 20.9%. The partial pressure of oxygen in the air is 20.9% of 407.1 inches WC, which is 85.08 inches WC.

Flue gas at atmospheric pressure may have an oxygen concentration of 3%. The partial pressure of oxygen in the flue gas would be 3% of 407.1 inches WC, which is 12.21 inches WC.

Flue gas at atmospheric pressure may have an oxygen concentration of 3%. Therefore, the partial pressure of oxygen in the flue gas would be 3% of 407.1 inches WC, which is 12.21 inches WC.

Standard zirconia probes are designed to vent the reference gas to the atmosphere, which pretty much assures the reference gas is very close to atmospheric pressure (407.1 inches WC absolute, 0 inches WC gauge).

Most of the applications in which zirconia probes are used to measure oxygen are low-pressure applications (<20 inches WC gauge). This means the total pressure of the process gas and reference gas are close, so errors in the measurement are minimal.

In higher process pressure applications (>20 inches WC gauge), the errors in the measurement can become substantial with non-compensated zirconia probes. This is because the increase in process pressure increases the partial pressure of oxygen, even though the % concentration of oxygen remains the same. Remember that the analyzer assumes that the only cause for an increase in the partial pressure of oxygen is an increase in % concentration.

See the scenarios below for a technical explanation:

Scenario 1:

Process at Atmospheric Pressure

- The reference side of the cell is at atmospheric pressure (407.1 inches WC).
- The reference side of the cell has an oxygen partial pressure of 85.08 inches WC (20.9% of 407.1).
- The process side of the cell is at atmospheric pressure.
- The process contains **10%** oxygen.
- Oxygen partial pressure of the process = (407.1 inches WC)(10%) = 40.71 inches WC.

At the Oxygen Probe

- Voltage produced by the cell = -50.74 log (oxygen partial pressure process side/oxygen partial pressure reference side)
- Voltage = -50.74 log (40.71 inches WC / 85.08 inches WC)
- Voltage = 16.2419 mV

Analyzer Calculations

- % Oxygen = 10 (50.74 log (partial pressure oxygen reference) – cell voltage / 50.74) / atmospheric pressure
- % Oxygen = 10 (50.74 log (85.08 inches WC) – 16.2419mV / 50.74)/ 407.1 inches WC
- % Oxygen = 40.71” WC / 407.1 inches WC
- % Oxygen = 10%

The Oxygen reading is accurate.

Scenario 2:

Process Pressure Increases by 5%

- Reference side of cell is at atmospheric pressure (407.1 inches WC).
- Reference side of cell has oxygen partial pressure of 85.08 inches WC. (20.9% of 407.1)
- Process side of cell is at 20 inch WC gauge (427.1 inches WC absolute).
- Process contains 10% oxygen.
- Oxygen partial pressure of process = (427.1 inches WC)(10%) = 42.71 inches WC

At the Oxygen Probe

- Voltage produced by the cell = -50.74 log (oxygen partial pressure process side/oxygen partial pressure reference side)
- Voltage = -50.74 log (42.71 inches WC / 85.08 inches WC)
- Voltage = 15.1864 mV

Analyzer Calculations

- % Oxygen = 10 (50.74 log (partial pressure oxygen reference) – cell voltage/ 50.74) / atmospheric pressure
- % Oxygen = 10 (50.74 log (85.08 inches WC) – 15.1864mV / 50.74)/ 407.1 inches WC
- % Oxygen = 42.71 inches WC / 407.1 inches WC
- % Oxygen = 10.5%

The oxygen reading has an error of 5%. The error is equal to the % increase in process pressure.

Scenario 3:

Process Pressure Increases by 10%

- Reference side of cell is at atmospheric pressure (407.1 inches WC)
- Reference side of cell has oxygen partial pressure of 85.08 inches WC. (20.9% of 407.1)
- Process side of cell is at 40 inches WC gauge (447.1 inches WC absolute)
- Process contains **10%** oxygen
- Oxygen partial pressure of process = (447.1 inches WC)(10%) = 44.71 inches WC

At the Oxygen Probe

- Voltage produced by the cell = -50.74 log (oxygen partial pressure process side/oxygen partial pressure reference side)
- Voltage = -50.74 log (44.71 inches WC / 85.08 inches WC)
- Voltage = 14.1779 mV

Analyzer Calculations

- % Oxygen = 10(50.74 log (partial pressure oxygen reference) – cell voltage/ 50.74) / atmospheric pressure
- % Oxygen = 10 (50.74 log (85.08 inches WC) – 14.1779mV / 50.74)/ 407.1 inches WC
- % Oxygen = 44.71 inches WC / 407.1 inches WC
- % Oxygen = **11%**

The oxygen reading has an error of 10%. The error is equal to the % increase in process pressure.

As the difference between total process gas pressure and total reference gas pressure increases, so does the measuring error.

Pressure Compensated Zirconia Probes

Pressure compensated probes are designed to equalize the reference gas pressure with the process gas pressure. To accomplish this, the reference gas is exhausted into the process at a low flow rate of 0.8 LPM. When the total reference gas pressure equals the full process pressure, the only cause contributing to the oxygen partial pressure differential is oxygen concentration in the process. This system also allows the process pressure to vary, as the reference gas pressure will float with the changes as long as it is flowing.

See the illustrations below:

Illustration of Standard (Uncompensated) Probe

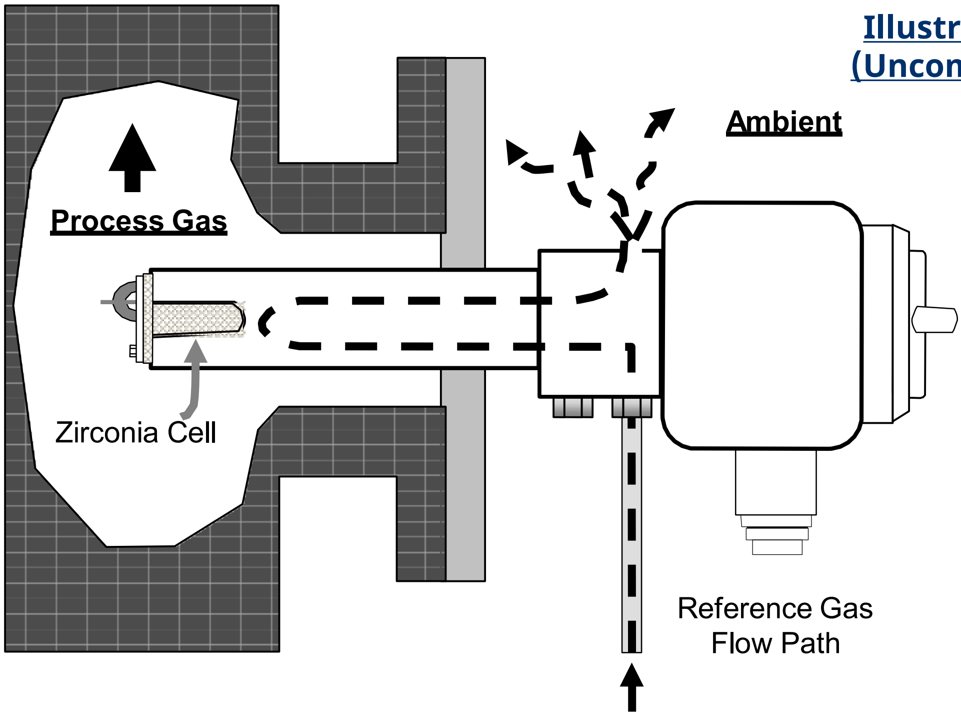
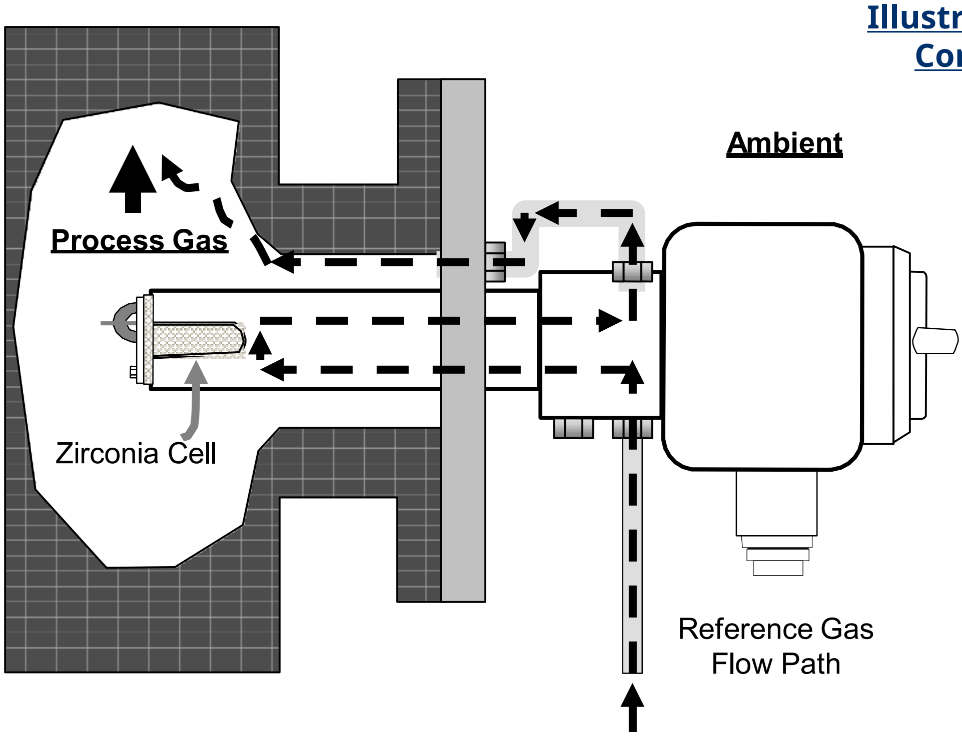


Illustration of Pressure Compensated Probe



Considerations

Most end-users should consider pressure compensated probes if the process pressure is greater than 20 inches WC. However, if the process pressure is this high and varies widely, pressure compensated probes are required to maintain an accurate measurement.

Ensure that the process can withstand having 0.8 LPM of air introduced into it and that the air can be easily dissipated downstream (no sleeves, protectors, or supports that will trap the reference air). Some applications cannot be "contaminated" with the reference air. One solution is to use a standard (non-compensated) probe and calibrate the probe insitu at process pressure for these applications. This will "calibrate out" the pressure-induced error and decrease the useful life span of the cell (cells have a zero-point correction up to 30%).

Please contact Yokogawa with any questions concerning this application.

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