Pressure Compensated Oxygen Probes (Zirconia)

What are pressure compensated O2 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 (normally clean, dry air) with a known O2 concentration on the other side. If there is a difference in O2 concentration between the process gas and reference gas, the cell will generate a voltage (mV). The bigger the difference, the bigger the voltage generated. The analyzer measures this voltage then calculates the O2 concentration.

The “force” that causes this voltage is actually 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“water column (WC) absolute pressure) has an oxygen concentration of 20.9%. The partial pressure of oxygen in air is 20.9% of 407.1”WC which is 85.08”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”WC which is 12.21”WC.

If the reference gas and process gas are at the same total pressure, the only thing that will contribute to the oxygen partial pressure differential is the concentration of oxygen on the process side.

Standard Zirconia probes are designed to vent the reference gas to atmosphere, which pretty much assures the reference gas is very close to atmospheric pressure (407.1 “WC absolute, 0 “WC gauge). Most of the applications where Zirconia probes are used to measure oxygen are low pressure applications (<20 “WC gauge). This means the total pressure of the process gas and reference gas are close, so errors in the measurement are minimal.

It is in higher process pressure applications (>20 “WC gauge) that the errors in the measurement can become substantial with non-compensated Zirconia probes. 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 thing that increases the partial pressure of oxygen is an increase in % concentration.

See the scenarios below for a technical explanation:

Scenario 1: Process at Atmospheric Pressure

Reference side of cell is at atmospheric pressure (407.1"WC).
Reference side of cell has oxygen partial pressure of 85.08"WC. (20.9% of 407.1)

Process side of cell is at atmospheric pressure.
Process contains **10%** oxygen.
Oxygen partial pressure of process = (407.1"WC)(10%)= 40.71"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"WC / 85.08"WC)
Voltage = 16.2419 mV

Analyzer Calculations

% Oxygen = $10^{(50.74 \log(\text{partial pressure oxygen reference}) - \text{cell voltage}/\ 50.74)}$/atmospheric pressure
% Oxygen = $10^{(50.74 \log(85.08\text{"WC}) - 16.2419\text{mV} / 50.74)}$/ 407.1"WC
% Oxygen = 40.71"WC / 407.1"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"WC).
Reference side of cell has oxygen partial pressure of 85.08"WC. (20.9% of 407.1)

Process side of cell is at 20"WC gauge (427.1"WC absolute).
Process contains **10%** oxygen.
Oxygen partial pressure of process = (427.1"WC)(10%)= 42.71"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"WC / 85.08"WC)
Voltage = 15.1864 mV

Analyzer Calculations

% Oxygen = $10^{(50.74 \log(\text{partial pressure oxygen reference}) - \text{cell voltage}/\ 50.74)}$/atmospheric pressure
% Oxygen = $10^{(50.74 \log(85.08\text{"WC}) - 15.1864\text{mV} / 50.74)}$/ 407.1"WC
% Oxygen = 42.71"WC / 407.1"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"WC).
Reference side of cell has oxygen partial pressure of 85.08"WC. (20.9% of 407.1)

Process side of cell is at 40"WC gauge (447.1"WC absolute).
Process contains **10%** oxygen.
Oxygen partial pressure of process = (447.1"WC)(10%)= 44.71"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"WC / 85.08"WC)
Voltage = 14.1779 mV

Analyzer Calculations

$\%\ \text{Oxygen} = 10^{(50.74 \log(\text{partial pressure oxygen reference}) - \text{cell voltage}/\ 50.74)} / \text{atmospheric pressure}$
$\%\ \text{Oxygen} = 10^{(50.74 \log(85.08\text{"WC}) - 14.1779\text{mV} / 50.74)} / 407.1\text{"WC}$
% Oxygen = 44.71"WC / 407.1"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 equilibrate 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 total process pressure, the only thing that will contribute to the oxygen partial pressure differential is the concentration of oxygen 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 (un-compensated probe)

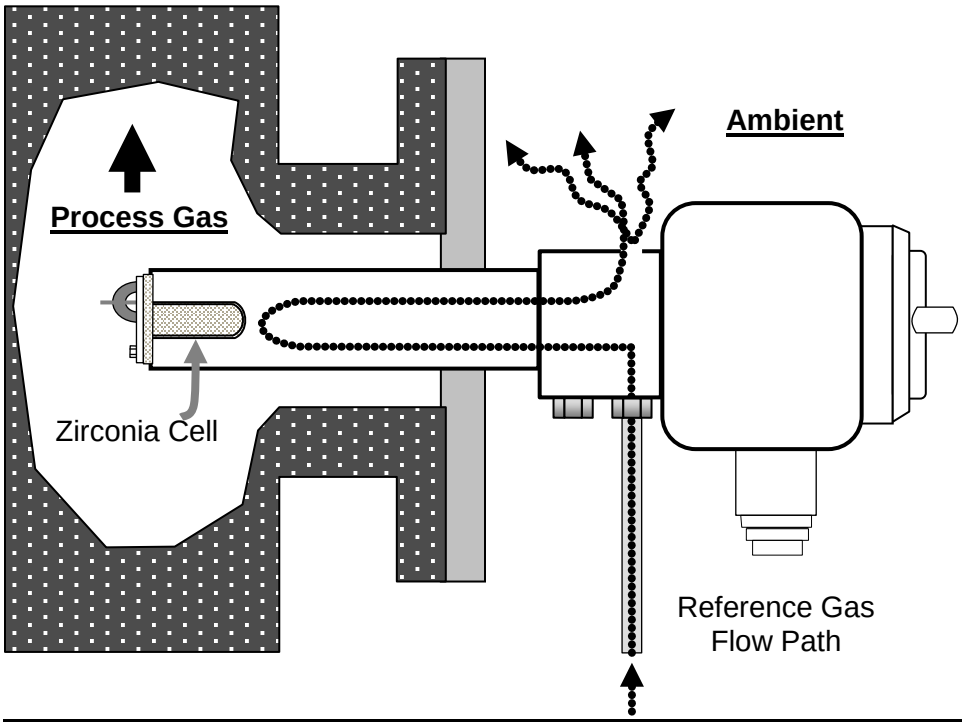
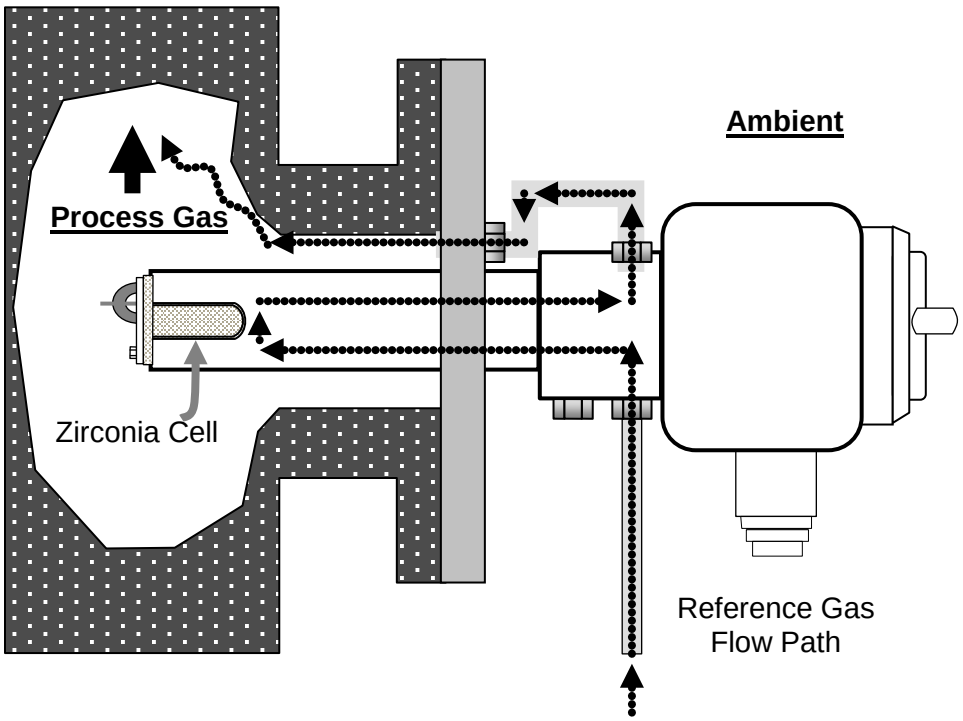


Illustration of Pressure Compensated Probe



Considerations

Most end users will want to consider pressure compensated probes if the process pressure is greater than 20 “WC. If the process pressure is this high, and varies widely, pressure compensated probes are required to maintain an accurate measurement.

Ensure that your 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. For these applications, one solution is to use a standard (non-compensated) probe, and calibrate the probe insitu at process pressure. This will “calibrate out” the pressure induced error, but will decrease the usable life span of the cell (cells have a zero point correction up to 30%).

If you have questions concerning your application, please contact your local Yokogawa representative.