SPEC Sensor Operation Overview

May 2016

SPEC Sensor™ Operation and Performance Considerations

Scope

This application note describes the principles of operation and performance considerations for SPEC Sensor™ electrochemical gas sensors.

1. Principles of Electrochemical Sensor Operation

SPEC Sensor™ are amperometric gas sensors, that is - electrochemical sensors which generate a current proportional to the volumetric fraction of the gas. A typical electrochemical sensor is shown with two electrodes in contact with a liquid electrolyte (Figure 1).

The gas is measured at the **working (or sensing) electrode**. This is usually a catalytic metal selected to optimize the reaction of the target gas. The gas being measured enters through the capillary diffusion barrier and reacts with the electrode. The electrons that result from the electrochemical reaction flow to or from the working electrode through an external circuit based on the amount of gas that is reacting, respectively. The working electrode current is the output signal of the sensor. The relationship between the working electrode current and the gas concentration is linear.

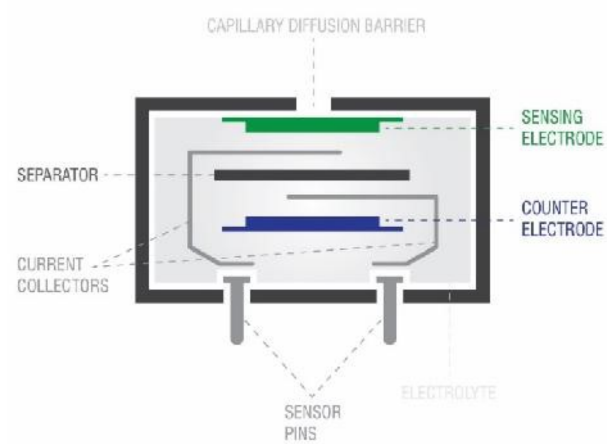


Figure 1: Typical 2 Electrode Electrochemical Gas Sensor

A **counter-electrode** is provided to complete the circuit of the electrochemical cell. The counter electrode functions solely as the second half-cell, and allows electrons to enter or leave the electrolyte in equal numbers and opposite direction of those involved in the working electrode reaction.

The addition of the third electrode, called the **reference electrode**, improves the stability, signal-to-noise ratio, and response time of the 2-electrode design by providing a stable electrochemical potential in the electrolyte that is normally protected from exposure to the sample gas. It is important that no current is allowed to flow through the reference electrode, as this would change its potential.

2. SPEC Sensor^{TM} Production Overview

In the past, electrochemical gas sensors have been bulky and hard to manufacture in high volumes. SPEC Sensors uses high volume plastic lamination and printed electronics techniques to make high performance electrochemical gas sensors in a thin, lower cost package.

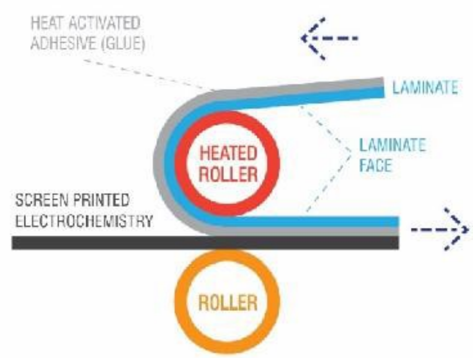


Figure 2 Overview of SPEC Sensors Production

This **S**creen-**P**rinted **E**lectro**C**hemical manufacturing process enables SPEC Sensors to provide the measurement performance and low power consumption operation of electrochemical sensors used for industrial safety, environmental sensing, and Home Carbon Monoxide sensors in a much smaller package designed for high volume manufacturing.

3. Potentiostat Operation

SPEC Sensors perform best when operated at a fixed bias potential. Table 1 shows the recommended bias potentials, for our current products.

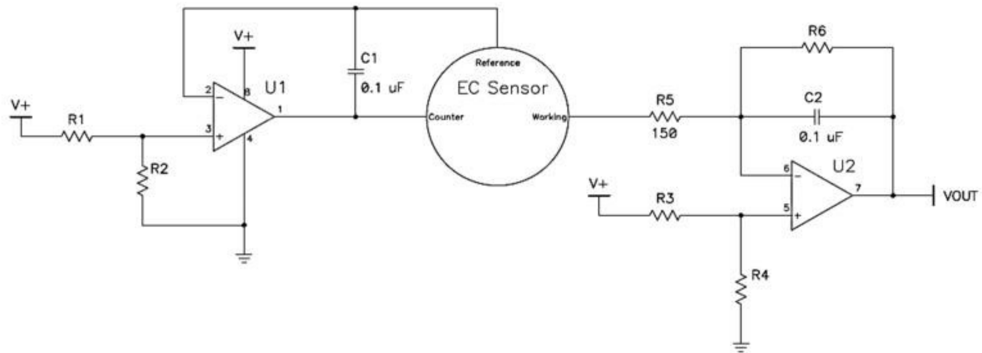
Sensor Part Number	Target Gas	Measurement Range	Recommended Bias
100102	Carbon Monoxide (CO)	1000 ppm	0 mV
100303	Hydrogen Sulfide (H2S)	50 ppm	0 mV
100601	Sulfur Dioxide (SO2)	20 ppm	0 to **+200 mV**
100401	Ozone (O3)	20 ppm	0 to **-200 mV**
100701	Nitrogen Dioxide (NO2)	20 ppm	-200 mV
100201	Ethanol	1000 ppm	+100 mV

TABLE 1: Recommended operating bias for the different sensors.

***NOTE**: in cases where a bias range is indicated, the recommended bias (based on all considerations) is indicated in **BOLD**.*

The circuit that controls the potential of the working electrode and converts the working electrode current to a voltage is called a potentiostat. A simplified diagram of a sensor and a potentiostat is illustrated in Figure 3. The potential of the reference electrode (RE) is established by a stable voltage at U1, pin 2. The potential of the working electrode (WE) is established by a stable voltage at U2, pin 5. The voltage at WE with respect to RE is known as the bias potential of the sensor. The working electrode (WE) current is converted to a voltage by operational amplifier, U2. . The op-amp, U1, generates a voltage at the counter electrode (CE) which is sufficient to supply a current that is exactly equal and opposite of the working electrode current.

Figure 3: *A simplified diagram of a three electrode electrochemical sensor and suggested potentiostat circuit.*



NOTES:
– A positive bias for the electrochemical cell is established by setting the voltage at U2, pin 5 with respect to U1, pin 3.
– The gain of the transimpedance amplifier is set with R6.
– Capacitors C1 and C2 and Resistor R5 can be adjusted to match the characteristics of the electrochemical cell.
– Analog or digital filtering can be implemented to improve signal–to–noise characteristics of the circuit.

4. Measurement Performance Considerations*:*

Several topics are discussed below, as they may impact the operation and measurement performance of the sensor:

- **A.** Power-On Stabilization
- **B.** Response Time & Linearity
- **C.** Short Term Environmental Effects
- **D.** Cross-Sensitivity to Other Gases
- **E.** Gas Sampling System & Material Considerations
- **F.** Characterization & Calibration
- **G.** Extreme Environment Operation
- **H.** Reliability and End-Of-Life Testing

A. Power-On Stabilization.

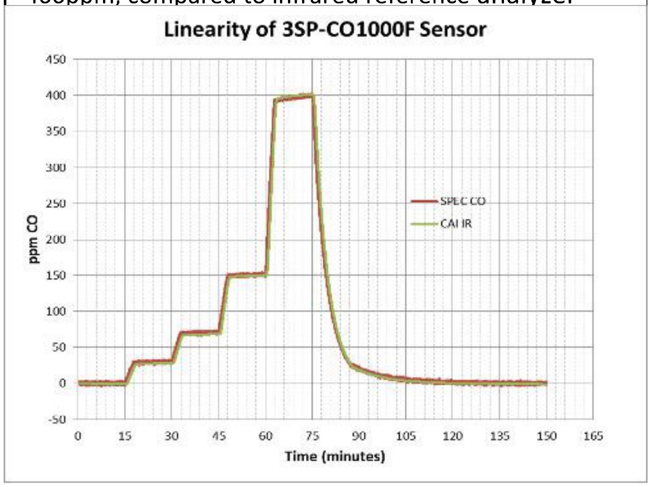
SPEC Sensors perform best when operated at a fixed bias potential. In instrument design, we recommend the bias should be “always-on" because allows the sensor to be in an "always-ready" status.

B. Response Time & Linearity

The electrochemical sensor gives a rapid response to the target gas. For example, the SPEC CO sensor typically reaches 90% of the full response to a step-change in concentration in <15 seconds. However, for accurate calibration, it is recommended that you expose the sensor to the target gas in the range of interest for at least a minute before adjusting span.

The sensor response is linear over a wide range of concentrations, typically over about three orders of magnitude before appreciable error in linear response can be detected. **Figure 6** compares the SPEC CO response to that of a reference IR CO analyzer. Therefore, for many applications, calibration can normally be performed with a single calibration gas. It is recommended that a concentration near the middle of the dynamic range is used for calibration.

Figure 6: Response of calibrated SPEC CO sensor, 0-400ppm, compared to infrared reference analyzer



C. Short Term Environmental Effects

All electrochemical sensors are affected by temperature because the reactions are temperature dependent. Fortunately, the temperature dependence of baseline/zero current and sensitivity/span is repeatable and easily compensated.

With respect to humidity, a rapid RH change can cause a spike in the baseline/zero current, which then rapidly re-stabilizes near its original level. Sensor sensitivity/span is not affected by short term RH changes.

SPEC Sensors are designed for use at ambient pressures, with minimal pressure or vacuum on the sensor face. However, the sensor output will vary approximately linearly with the pressure.

SPEC Sensors are calibrated under standard conditions (23 ± 3 °C, 40 - 60% RH, and sea level atmospheric pressure). For highest accuracy, SPEC Sensors recommends calibrating the sensors at the intended usage pressure.

D. Cross Sensitivity to Other Gases

SPEC Sensors are designed for optimum response to the target gas.It's possible that "interfering" gases that may be present along with the target gas can create false signals (either positive or negative). See the datasheet for each gas sensor for more detailed data regarding cross sensitivities to the most common interfering gases.

E. Gas Sampling System & Material Considerations

The sensor should be protected at all times from dust, oils, and condensed moisture. A porous particulate filter should be mounted over the gas exposure holes of the system enclosure. If moisture does condense on the sensor, the signal and response time may noticeably decrease . Once the condensing environment is eliminated, and the moisture dries, sensor performance will typically return to normal.

It is critical in product design to protect the sensing face of the sensor from accumulation of dust and oils. This can be accomplished with a *replaceable* gas-permeable membrane. When dealing with very reactive gases, such as H_2S, NO_2, SO_2 and O_3, material selection is important. Care must be used in selecting all materials, including but not limited to enclosures, tubing, manifolds, pumps and valves.

Common thermoplastics such as ABS and styrene will rapidly scrub out trace levels of gases such as H_2S, NO_2, SO_2 and O_3due to surface adsorption of these molecules. Aluminum, copper, and polymers such as Nylon and most rubber variants tend to adsorb or react with these gases. If surface adsorption occurs on the exposed materials, the concentration reaching the sensor will be decreased, until the surfaces are saturated. Once the gas is no longer present in the sample, the adsorbed molecules may desorb from the surfaces and can then be detected by the sensor. This may appear to the user as a slow sensor recovery.

It is recommended that one minimize materials to which the gas is exposed before reaching the sensor. Wherever possible Teflon™, polypropylene, or stainless steel should be used. Delrin and polycarbonate are suitable where close tolerances are required in machined/molded parts, and Viton™ and EPDM are relatively inert materials that may be used in seals and pump diaphragms.

NOTE: Electronic self-test methods cannot detect loss of response caused by lack of gas diffusion when dust or water droplets cover the gas port of the sensor. Not even a perfectly functional gas sensor will respond if the gas does not reach the sensing electrode. It is critical in product design to protect the sensing face of the sensor from accumulation of dust, oils, and water. This can be accomplished with a replaceable gas-permeable membrane.

F. Characterization & Calibration

Product applications and product system design can strongly influence the performance of any sensor, including SPEC Sensors. For best results, we suggest that each product designer characterize the SPEC sensor in the final application. We guarantee the highest quality electrochemical sensor product and we are committed to assisting you in every way we can to obtain the optimum performance from our product. We recommend that you use our engineering data as a starting point, not an end point. Do not use SPEC Sensors' data sheets to replace your product evaluation data. Consult the individual data sheets for each sensor's performance. Please feel free to consult SPEC Sensors anytime with questions regarding sensor operation or application.

G. Extreme Environment Operation

Continuous operation (10 days+) at low relative humidity (< 15%) and/or high temperatures (> 40 °C) can cause loss of sensor sensitivity (nA/ppm) in some sensors. Loss of sensitivity is temporary, the sensors can recover when exposed to more humid conditions.

H. Reliability and End-of-Life Testing

The working electrode functions as a catalyst for the electrochemical reaction of the analyte, but is not itself reacted or consumed. Thus, under ideal conditions, the sensor will exhibit a stable response for an indefinite period of time. For typical indoor environmental conditions (23 ± 3 °C, 50 ± 20% RH),a 10 year operating life is expected. Our current long term testing has shown a failure rate of < 1.3 failures per million hours of operation (FPMH). Expressed differently, this illustrates a minimum mean time between failures (MTBF) of >790,000 hours (>90 unit-years!) cumulative operation. For these tests, failure is determined by the UL2034 sensitivity requirements.

AN-110 SPEC Sensor End of Lifetime Self-Test was written specifically to guide designers of Home CO detectors in developing a "supervisory circuit" per UL2034 Standard. The information can be applied to other SPEC Sensor products and helps to check for several modes of failure, wire breakage, short-circuit, and dry-out of the liquid electrolyte from extreme environments.