Technical Note No. 066
Use and Limitations of Low-Cost Electrochemical Sensors in Air Quality Measurements

Date: 12 December 2024
Author: Andrew Turnipseed

Summary

This Technical Note provides guidance for using electrochemical sensors when applied to air quality monitoring as well as understanding their limitations. This Tech Note applies to the following 2B Tech instruments that use these sensors: AQLite (standard) Air Monitoring Packages, AQSync Air Quality Monitoring Stations that were custom ordered to use a sensor to measure carbon monoxide or other species, and Personal Air Monitors (PAM) previously offered by 2B Tech.

Tools/Materials Needed

none

Introduction

Over the past few years there has been an enormous surge in interest in the application of low-cost sensors to conduct measurements of air pollutants by educators, citizen scientists, and groups interested in air pollution levels within their own communities. Indeed, it is now recognized that sensors can fill important gaps that are virtually impossible to fill with conventional or even miniaturized instruments because of their low cost, small size, and ease of deployment. However, the limitations of sensors must be recognized and care must be taken to obtain meaningful results. 2B Tech incorporates low-cost electrochemical (EC) sensors in its AQLite and AQSync measurement platforms, and in its previously offered Personal Air Monitor (PAM). The EC sensors used by 2B Tech are manufactured by Alphasense – a leader in EC sensor technology.

When using EC sensors for measuring ambient level pollutants one must keep in mind that these sensors were originally developed for industrial health and safety applications and were primarily used to detect relatively high concentrations (> 1 to 100 ppm). Applying these sensors to the lower pollutant concentrations (~ 10's of ppb) typical of ambient air can be challenging. At 2B Tech, we routinely incorporate EC sensors for measuring carbon monoxide (CO); primarily because background CO concentrations tend to be ≥ 0.1 ppm, with urban levels extending upwards to several ppm. Other pollutants that can be measured by EC sensors (e.g, NO_2, O_3, SO_2, H_2S) tend to have ambient concentrations < 0.1 ppm. At these levels, effects of environmental changes, sensor noise and cross-sensitivities to other species are magnified. Therefore, we do not include these sensors in our measurement packages without prior discussion of a customer's specific application.

In this Tech Note, we give some practical recommendations for using EC CO sensors for ambient air quality measurements. Although our recommendations are focused on CO sensors here, we will then mention how these ideas extend to other EC sensors. Our Tech Note 065 focuses on low-cost particulate matter (PM) sensors.

Recommendations for EC CO Sensors

(1) *Field Intercomparisons with reference instruments are necessary for best accuracy.* At 2B Tech, we derive calibration coefficients (a zero offset and span) for EC CO sensors in the lab using gas standards. We have typically found that CO sensors calibrated in this way provide *good relative* measurements (i.e., they track CO concentrations well over time). However, significant zero offsets have been observed once deployed in the field (± 0.4 ppm or more). Comparing with nearby measurements from reference-grade instrumentation tends to be the most effective means of deriving correct calibration coefficients applicable to ambient conditions. This is supported by recent reports by the World Meteorological Organization (Lewis et al., 2018; Peltier, 2020). They conclude that laboratory-based EC calibrations are not always valid under ambient conditions and that intercomparisons in ambient air with established reference techniques provides the most reliable method of calibrating measurements from EC sensors.

(2) *Sensitivity degradation*. CO sensor sensitivity slowly degrades over time – partially due contamination of the porous membrane that allows diffusion of pollutants into the EC sensor. Particulates are not filtered in the PAM and AQLite sample air, therefore, contamination is more rapid and EC sensors should be either replaced or re-evaluated every 4-6 months. The air is filtered in the AQSync, thus, degradation is slower and EC sensors can be used for longer periods – up to a year of continuous use. CO sensors can be easily swapped (*contact 2B for procedure*); however, the original lab-derived calibration coefficients are likely no longer valid and should be re-evaluated.

(3) *Temperature* affects both the sensitivity (or span) and the zero offset (signal at CO = 0). Specification Sheets provided by Alphasense indicate the sensor sensitivity roughly changes about 1% per °C (from 0 and 30 °C) and is moderately consistent across sensors (Figure 1). Temperature impacts on sensor offsets are generally nonlinear, exhibit more sensor-to-sensor variability, and have a larger impact at temperatures > 25-30 °C (see Figure 2). In general, the CO offset becomes increasingly more negative at high temperatures. Note that with a typical

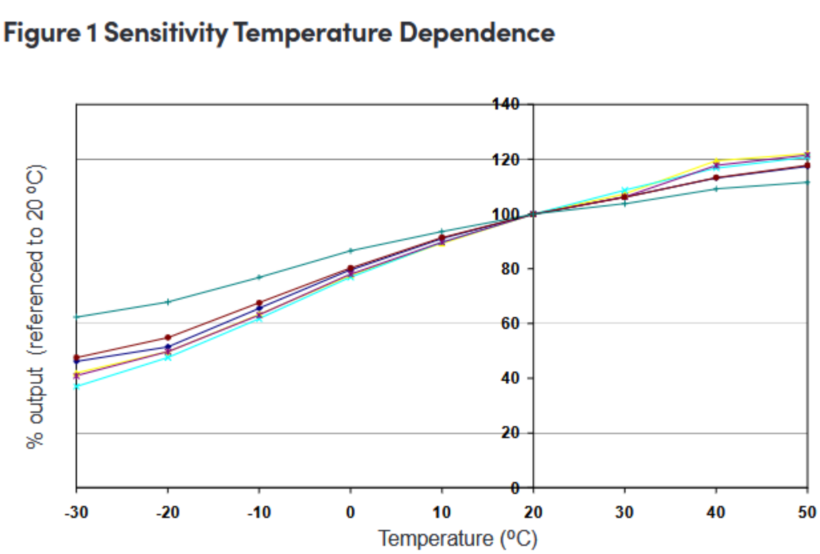

Figure 1. The CO sensitivity of a typical batch of EC sensors as a function of temperature. Sensitivity is normalized to 100% at 20 °C. Figure reproduced from Alphasense Specification Sheet.

sensor sensitivity (~350 nA/ppm), an offset of -100 nA is equivalent to -0.35 ppm. The large sensor-to-sensor variability makes it difficult to apply any simple temperature correction for the offset. However, temperature changes below about 25 °C tend to have small impacts on measured CO concentrations.

(4) *Humidity* effects on EC CO sensors are often transient (see [Alphasense Tech Note AAN 110]) and observed during rapid humidity changes. This effect is very difficult to both elucidate or correct. However, ambient humidity typically changes slowly enough that the effects on CO measurements are fairly small (< ± 0.2 ppm), such that 2B Tech does not currently recommend any method for correcting humidity effects.

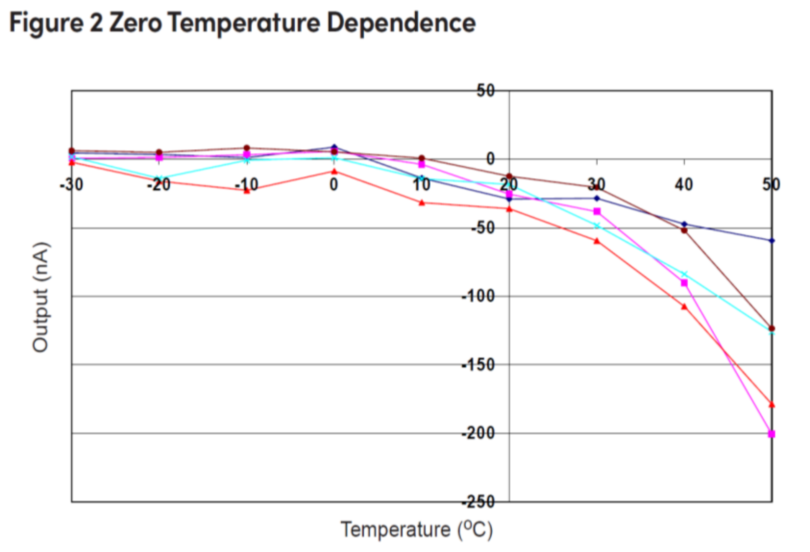

Figure 2. The signal offset of a typical batch of CO EC sensors as a function of temperature. Figure reproduced from Alphasense Specification Sheet.

Electrochemical Sensors for Other Pollutants

EC sensors are also available that target many other pollutants such as NO_2, SO_2, and H_2S. In general, the same recommendations given above apply to these sensors as well; however, these sensors should be used with more caution when applying them to measurements in ambient air. The EC sensors that target these species have similar absolute sensitivities as the CO sensor, and the impacts by temperature and humidity are of similar magnitude, but these pollutants are generally observed at much lower concentrations than CO. This essentially magnifies the effects of temperature and humidity. For example, a temperature change between 20 to 30 °C can easily alter the offset output of an EC sensor by ± 10 nA (see Figure 2). Since both CO and NO_2 sensors have approximately similar absolute sensitivities (~ 350 nA/ppm), a 10 nA signal change is equivalent to ~ 30 ppb (10 nA/350 nA/ppm = 0.029 ppm = 29 ppb). This is a relatively small amount compared to typical CO concentrations, but not for NO_2. In fact, ambient levels of NO_2 are often only about 30 ppb and rarely extend above 100 ppb. Thus, for EC NO_2 measurements, it becomes critical to compensate even for moderate changes in environmental variables. These corrections can be substantial and difficult to apply uniformly across multiple sensors.

A further concern for some EC sensors is that they respond to other pollutants in addition to the intended target species (referred to as a “cross sensitivity”). For example, the SO_2 sensors exhibit significant negative responses to both NO_2 and O_3. Therefore, measurements of NO_2

and O_3 (each with its own associated measurement uncertainties) are typically required to correct the observed SO_2 sensor response. These corrections can be relatively large, especially if the interfering species is at a much higher concentration than the target pollutant. In any case, these corrections always increase the uncertainty of the target pollutant measurement.

Overall, when using any EC sensors for ambient air quality measurements, it is always critically important to understand the typical concentration levels of the target pollutant one wants to measure compared to the limitations of the specific sensor. Limitations in EC sensors arise from the sensor responses to temperature and humidity changes as well as cross sensitivities to other species that could be present for a given application. A general rule of thumb would be that concentration variations below about ± 20 are difficult to accurately discern when using EC sensors. Furthermore, it appears that laboratory-derived calibrations and correction algorithms (i.e., for temperature or cross sensitivities) are not always applicable once the EC sensor is deployed measuring ambient air. The reasons for this are not fully understood, but it seems clear that measurement comparisons to more established instrumental techniques in ambient air are required to reduce EC sensor uncertainties to levels where meaningful pollutant concentrations can be obtained.

References

Lewis, Alastair, Peltier, W. Richard and von Schneidemesser, Erika (2018) Low-cost sensors for the measurement of atmospheric composition: overview of topic and future applications. Research Report No.1215, World Meteorological Organization (WMO), Geneva, Switzerland. https://eprints.whiterose.ac.uk/135994/

Peltier, Richard W. (editor) (2020), An update on low-cost sensors for the measurement of atmospheric composition, Research Report No. 1215, World Meteorological Organization (WMO), Geneva, Switzerland. https://library.wmo.int/records/item/37465-an-update-on-low-cost-sensors-for-the-measurement-of-atmospheric-composition#.YL3zF0w8y70