DOI 10.5162/IMCS2018/P2EM.8

Gas Sensor Evaluation: Path to Research, Development, and Market Success: Example of Electrochemical Sensors for IoT and Air Quality

Joseph R. Stetter, Ph.D.
KWJ Engineering Inc. and Spec-Sensors LLC, 8430 Central Ave., Newark, CA 94560 USA
Corresponding Author: jrstetter@gmail.com

Abstract

The Internet of things [IoT] will make the impact of air quality [AQ] sensors immense on both quality and length of human life. To reach the IoT applications, improved sensors are required with a uniquely disruptive set of characteristics that include simultaneous performance while being tiny low cost and long life with virtually no maintenance. We report here the applications of the amperometric gas sensor or AGS [1] in sensor systems that will impact human health and environmental measurements. Sensor evaluations are the key component in both sensor research and sensor applications. Operando Methods [2] are a good example of sensor characterizations that lead to understanding sensor mechanisms while comprehensive environmental measurements are used to predict performance in specific applications [3]. Both approaches can aid understanding of the mechanism of operation of a sensor and lead to advances in research materials and devices. The predictive power of the latter characterization approach provides a path to market success and will link the sensor to applications for the benefit of society.

Key words: low cost, air quality. Electrochemical, gas sensor, Internet of things, wellbeing.

Introduction

The major outdoor AQ sensors include: CO [carbon monoxide], NO2, SO2, O3 and VOCs as well as particulate matter. Indoor AQ, however, includes many others such as CO2, O2, and H2CO. And industrial AQ can include a vast number of industry specific gases including but not limited to H2S and Cl2. Specific AGS AQ sensors and the IoT will enable people to live better, improve wellness, and change the world if they can be deployed successfully.

The IoT is taking many forms and some envision communicating devices that are global networks providing instantaneous information. Others talk about a cloud that services a specific community with vital data, Still others envision a smaller version, sometime called the "fog" or very localized specific purpose system. In all cases, there is a reliance on systems that comprise sensing-computing-communicating [SCC] devices coupled to cloud-type awareness capability.

The often-missing link is the understanding and algorithm to turn sensory data into actionable information. The information must be available for use at the pace of life [fast] and for little or no extra cost in order to be successfully deployed in large numbers.

Air quality sensors must have business impacts. In fact, for any AQ sensors to succeed and accomplish positive societal impacts, there must be a commercial driver pulling it into the application. AQ/IoT impacts many areas including personal healthcare, real-estate, industrial safety, smart-cities, transportation, tourism, medical diagnosis and monitoring, and environmental monitoring and regulation. In all cases, Sensor evaluation [characterization] will be a technical driver for success of SCC devices and a tech-driver of future GDP growth.

Experimental Sensor Characterization

The starting point for evaluating a gas sensor, be it for applications or for sensor development, is measurement of the sensor signal often expressed as:

$$S = [S_x - S_0] \text{ or } S/S_0 = [S_x/S_0 - 1]$$

and S is the signal, Sx is with the target gas and S0 without.

The origin of variation in the signal comes from exposure to variation in the target gas analyte plus any other parameter that effects the AGS sensor such as T, P, RH that can add to or subtract from the signal. In our model, an over simplified interpretation would express this as:

$$DS = dS/dC*C' + dS/dRh*Rh' + dS/dT*T' + dS/dP*P' + dS/dt*t$$

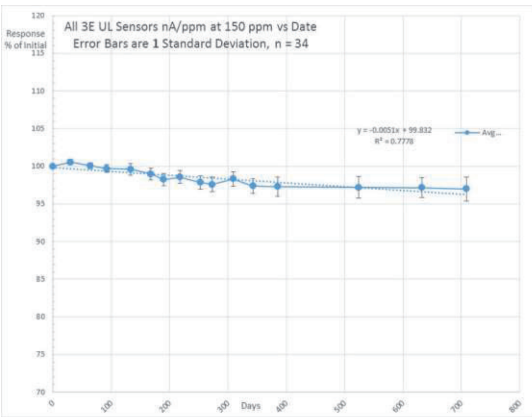
where these are partial differentials and the last variable is time [sensor drift]. This simplified model ignores the selectivity challenge, vibration, and other variables, and we note that the changes over time can be more than an additive term as there can be complex chemical reactions and aging phenomena in a sensor's history. The final compensation and accuracy of the sensor depends upon how well we are able to model each of the terms and extract the true or accurate value for coefficients and ultimately the predict the desired concentration.

Results and Discussion

The operando method is most interesting because its powerful approach is a result of characterization of the sensor signal using simultaneously measurements of different parameters. Reports illustrate this approach for Heated SMOx sensors. Electrochemical sensors for AQ and IoT applications [1, 5] are evaluated using the model above [3] and result in a certified [UL] part that can bridge the cost-performance gap to success in markets.

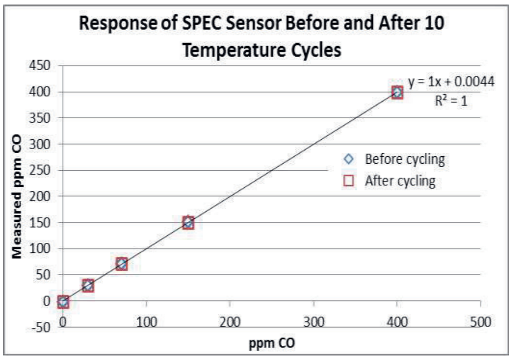
Predictive Data for CO sensor

Prediction of stability over T, P, RH, time is address by evaluating a large lot of sensors and then using a model to predict MTBF [mean time between failure]. We applied this to the AGS by evaluating 129 sensors simultaneously over 1-3 years with perioding calibrations against a

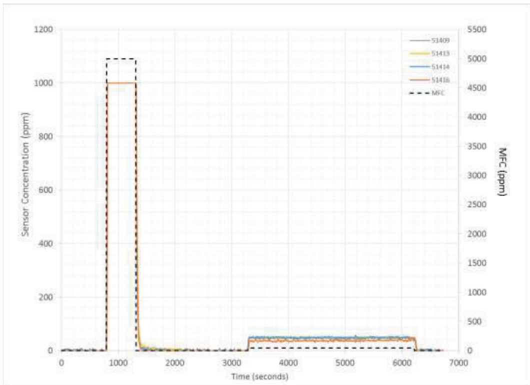


certified NIST traceable standard for CO. Two years of data above illustrate stability over time at 50% RH and 0-400ppm CO. The MTBF [5] for 129 sensors for 15, 185 hrs with 0 failures provides for 97 years mtbf or 1.2 FPMH [failures per million hours and a projected failure rate of <0.38 in 10 years. Of course, we will continue to test until failure.

Additional evaluation predict performance under dry condition, variable temperature [below], and with interferences.



EN50291 test of exposure to 6000 ppm with recovery to <50 ppm in <120 sec exceeds the 15 min. requirement. A dozen additional tests



are reported to predict field performance. Comprehensive testing is the path to model development herein and commercial success.

References

[1] Joseph R. Stetter and Jing Li, i "Amperometric Gas Sensors – A Review," Chemical Reviews, 108 (2), 2008, pp352.

[2] R. Moos, K. Sahner, M. Fleisher, U. Guth, N. Barsan, U. Weimar,"Solid-state Gas Sensor Research in Germany, a status report," Sensors, 2009, 9(6), 4323-4365.

[3] J. R. Stetter, "Experimental Methods in Chemical Sensor and Sensor Array Evaluation and Development," in "Computational Methods for Sensor Materials Selection, M.A. Ryan, A.V. Shevade, C.J. Taylor, M.L.Homer, M. Blanco, and **J. R. Stetter**, editors, 2009, pp3-46.

[4] M. Hubner,et. al., Phys. Chem. Chem Phys., 2012, 14, 13249. And K. Grossmann, ibid 2013, 15, 19151.

[5] See www.spec-sensors.com; usPatent 8795484, http//reliabilityanalyticstoolkit.apps.com/field_mtbf_calculator.