WHAT IS MY GAS SENSOR LIFETIME?

"How long will my gas sensor last?"
"When do I need to replace my electrochemical gas sensor?"

CoGDEM
The Council of Gas Detection and Environmental Monitoring

These questions haunt gas sensor manufacturers and a clear, unified answer is needed. A further complication is the warranty period, which varies between the manufacturers, often driven by marketing and finance departments is not based on actual sensor lifetime. Both domestic CO and industrial safety sensor suppliers want to feel more secure with their lifetime statements.

Historically, sensor lifetime has been based on each manufacturer's view, based perhaps on sensor return rates or market demand. Currently manufacturers selling products into the residential Carbon Monoxide safety market refer to domestic CO detector standards: EN 50291 and UL 2034 (ASTM D6332). Whilst EN50291 has been regularly updated and now requires the manufacturer to provide an end of life indication, neither prescribes a means to establish sensor lifetime based on analysis of failure mechanisms. The industrial safely industry references EN 45544, which only requires relatively short term testing and therefore can not elucidate sensor lifetimes.

CoGDEM created a sub-group of sensor manufacturers in 2018 to re-approach the question of electrochemical gas sensor lifetime. The sub-group includes Alphasense, City Technology, Draeger, Ei Electronics. DD Scientific. Figaro, HH60 Consultants, Kane International, Kidde Safety, New Cosmos, Riken Keiki, Sprue Safety and Weatherall Equipment.

The sub-group agreed a plan with four milestones:

1. What are the failure mechanisms? Failure Mode and Effects Analysis (FMEA) was sent from each sensor manufacturer to the CoGDEM administrator who collated anonymously their FMEA reports.
2. Relevant failure mechanisms from the consolidated FMEA reports were used to define the tests that stress the sensors for these failures.
3. We consulted internally and with academics for the underlying electrochemistry and mechanical sources of these failures and developed test procedures and specifications that exercise the sensors in a reasonable timescale and cost. Statistics were emphasised.
4. The domestic CO and industrial safety sub-group provided a test specification that was agreed amongst sensor manufacturers. This will hopefully generate in the future BSI, then CEN, then ISO standards.

The goal of the sub-group is that we all report sensor performance, using a consistent test specification. This will drive the standards bodies to update lifetime testing, starting with our test specifications.

Where are we?

FMEA

The table summarises our mutual conclusion of electrochemical gas sensor failure modes.

Figure 1 Extract from FMEA

Design Decision	Failure Mode	Symptom(s)	Test
Pin / body design, Body welding/sealing	Leakage (External)	External residue	Temperature cycling - Durability Test
Catalyst/electrode design/ manufacture, Type of catalyst, Bias Voltage	Loss of catalytic activity, poor selectivity	Sensitivity drift outside specification, Zero Current too high, Reduced sensitivity, Poor sensitivity tempco, Slow t90	High Gas Concentration Exposure - Catalyst Degradation

Failure mechanisms

Following review of the FMEA, the group decided that some failures did not affect the lifetime: they were due to either manufacturing defects or were application-specific. Having isolated these failures, we concluded that the two underlying failures that determine lifetime were either sensor catalyst degradation or mechanical fault. Catalyst degradation is the primary source for sensor failure.

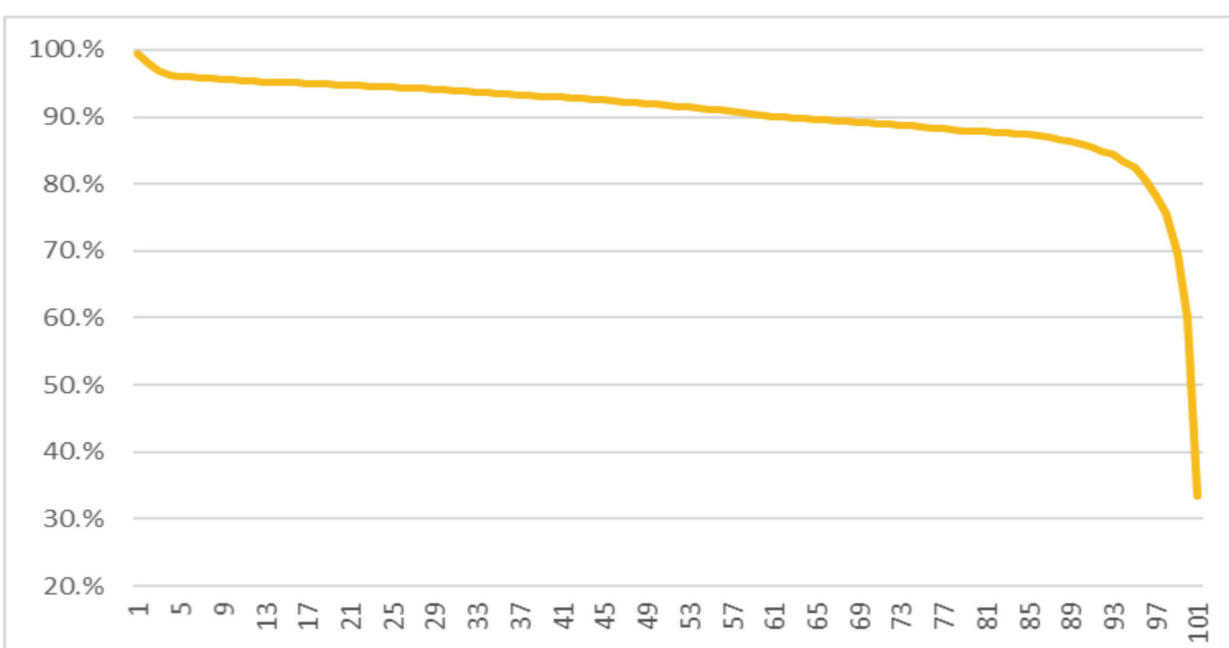
Electrochemical gas sensors generally have three periods in their lifetime:

Initial stabilisation can require from days to months, depending on the catalyst, application and required resolution. Sensor manufacturers normally stabilise electrochemical gas sensors before shipping.

After initial stabilisation, the sensor will perform reliably, showing a slow decrease in output- the rate of loss of output depends on the sensor catalyst and application. Generally, sensor output will remain predictable for many years.

Eventually the sensor output will decrease rapidly and response time will increase significantly. The catalyst is exhausted and the sensor is no longer reliable. The time when sensor performance decays rapidly is the end of life, although the sensor will still respond to test gas.

This figure shows typical output vs. lifetime. The intercept of the stable plateau and decreasing performance is defined as the Failure Point.



Scientific Support

Accelerated lifetime testing has been studied by IBM for 50 years, focusing on silicon technology; we extrapolated this understanding to chemical sensors, and understanding the underlying sensor chemistry is critical. Traditional acceleration rates of twice per 10°C is common in wet chemistry and has been used in gas sensor testing, but catalyst technology does not work to these rules, unfortunately. Testing at 50°C accelerates the lifetime testing by only about 30% for most catalysts, not 300% to 500%.

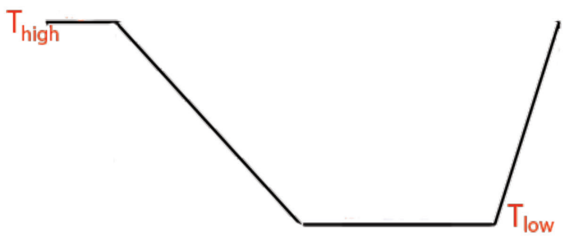
The alternative approach is to treat the amperometric sensors as batteries (gas being the fuel) and to operate them at accelerated currents, following how batteries are tested. We must ensure that the accelerated testing is within the linear range of the sensor's performance, otherwise alternative failure modes may give false results.

What can we achieve? We believe that domestic CO sensors claiming 10 year lifetime should be capable of being accelerated tested in 12 to 20 months to confirm a 10 year lifetime.

The CoGDEM group now have a draft test specification with two required tests for mechanical stability and catalyst lifetime. Optional tests for FGAs, high humidity testing, particle and interfering gases are also included. Statistical analytical tools for gas sensors are also defined.

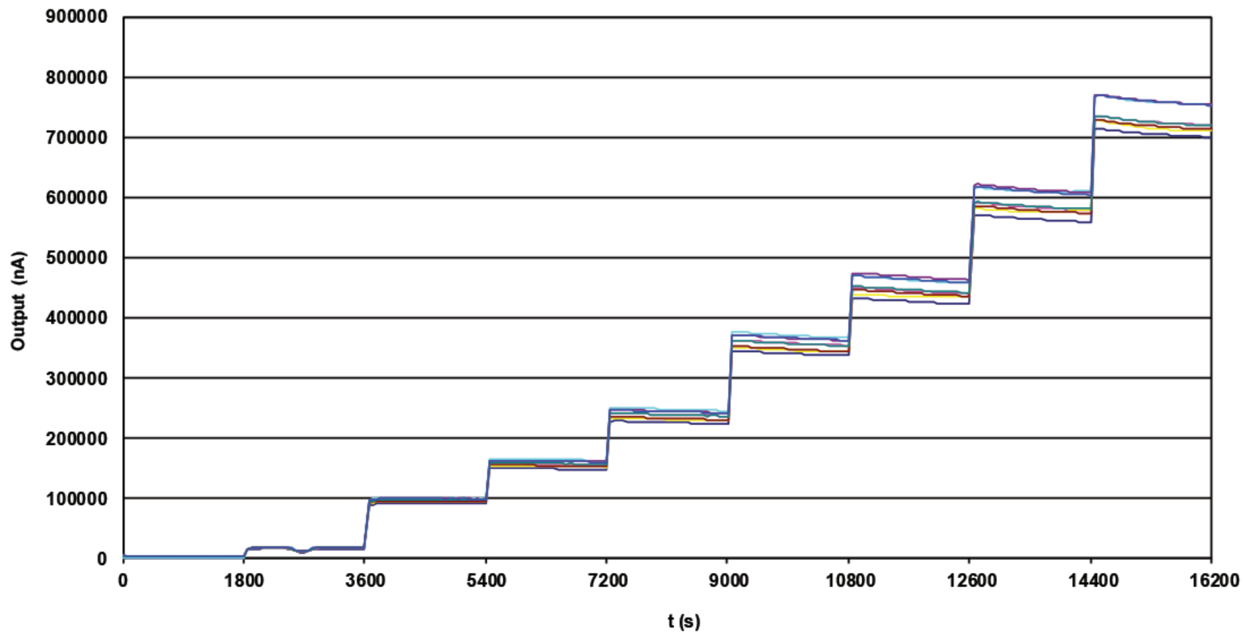
Required Tests

Most electrochemical sensors contain a liquid electrolyte, even those in which the liquid is dispersed in a gel matrix or organic based. Such devices are susceptible to leakage past internal seals, so the first key test uses a cyclical heat exposure to stress the seals, looking for leakage. The manufacturer's minimum and maximum temperatures are used with a 30 minute dwell time at each temperature and a 2-4K/ min ramp rate. The test is stopped when either half of the sensors have failed or the test has run beyond the level required to demonstrate the stated life.



The sample size should be at least 30 sensors and the time each sensor survives is recorded.

The second required test is a catalyst degradation test, designed to accelerate the normal loss of activity seen over the lifetime of a sensor. Electrochemical sensors generate a current when the electrocatalyst on the sensing electrode promotes the reduction or oxidation of the target gas, producing or consuming electrons in proportion to the gas concentration. The ability of the electrocatalyst to function gradually degrades over the sensor life, generally faster in applications where sensors are used at higher gas concentrations. For example CO sensors stored in clean laboratory air have shown little degradation after 15 years, but sensors used to measure flue gas as part of routine boiler servicing are often replaced every 2 to 3 years.



The catalyst degradation test is therefore designed to generate higher currents from the sensor than normal, through a combination of exposure to very high gas concentrations and the use of special test sensors with larger outputs than the standard sensor.

Sensors with increased outputs are first tested to define the maximum stable test gas concentration using an increasing stepwise gas concentration, and the highest stable gas concentration is determined. In the example opposite 250 μA is the highest stable concentration. The sensors are then exposed either continuously or intermittently to this test gas.

To measure the degree of catalyst degradation during the test, sensors are periodically removed and the response time plus the ratio of the output at -20°C to the output at ambient to the target gas is measured. An increase of the sensitivity ratio at these two temperatures is a sign that the catalyst is degrading.

Processing the Data

Typical performance tests are type approval tests which confirm that a sensor design is capable of meeting a requirement; but the small sample size, product performance variability and where the requirement concerns safety (such as use in hazardous areas), further Quality Assurance requirements may be imposed. The CoGDEM lifetime specification recognises this and by requiring larger sample sizes allows an estimation of both the mean failure time and the likely variability assuming the sample is representative of current production.

MTTF for the durability is calculated and may be used to compare different products or to confirm that a particular product has shown an acceptable level of performance.

The catalyst degradation determines the mean Coulombs produced over the sensor lifetime and may be used as a comparison of products or related to an application requirement. For example, a sensor design which produced 10 Coulombs in the accelerated test and would normally have a 50nA/ppm output could have a minimum life when exposed to 1ppm continuously of:

$$Min\ Life = \frac{10}{50*10^{-9}}\ \text{secs}$$

Or approximately 6 years.

This CoGDEM test specification creates a standardised way of comparing the lifetimes of different sensors. This is not a standard, although we hope in time it will be integrated by standards committees. It is appreciated that failures due to mechanical destruction, poisoning or poor housing design are not included in this specification.

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