Intrinsic Safety
Information for Electrochemical Gas Sensors

Introduction This document provides a background to the intrinsic safety information provided for DD-Scientific's range of electrochemical toxic and oxygen gas sensors.

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1. 1.0 Introduction

DD-Scientific electrochemical gas sensors are devices that typically only produce very small currents and voltages that are not able to store large quantities of energy.

Thus, considering the electrical characteristics of the sensors in normal operation and the possible fault conditions, DDS sensors can be considered as "simple apparatus" as defined in BS 5501 Paragraph 1.3 of the 'general requirements' states that:

"Devices in which, according to the manufacturer's specifications, none of the values 1.2V, 0.1A, 20uJ, or 25mW is exceeded need not be certified or marked."

The purpose of this application note is to explain sensor output during normal use and sensor output during a system fault or when changing sensors. This application note applies to all our range of toxic gas sensors.

2.0 Toxic Sensors

2.1 Currents and Voltages generated during normal use at 20°C.

DD-Scientific toxic gas sensors (e.g. carbon monoxide and hydrogen sulphide sensors) are linear over the recommended operating range of gas concentration and the current generated is given by the following equation:

Gas concentration (ppm) x sensor sensitivity (uA/ppm) = sensor output (uA)

The linear relationship fails when the sensors are exposed above their recommended concentration range, which results in severe polarisation at the counter electrode.

The sensing electrode is controlled, relative to an unpolarised reference electrode, by an external operational amplifier circuit and the sensing electrode potential is independent of the counter electrode polarisation. The maximum current limitation of amplifiers commonly used with a sensor control is unlikely to exceed 50mA.

2.2 Voltages Generated

In normal operation the maximum sensor voltage generated is the sum of the sensing-reference and reference-counter potentials.

For zero voltage biased sensors, the sensing-reference potential will be zero or very close to zero (<10mV). However the counter electrode potential is free to float relative to the reference electrode and will polarise as it produces the required cell current. This degree of polarisation is dependent on time and concentration, however once a polarisation of 1.05V has occurred the counter electrode will start to evolve hydrogen and no further polarisation can take place. This equates to the maximum theoretical sensor voltage for an unbiased sensor is 1.05V.

For biased sensors the reference-counter potential applies equally to biased sensors, but the sensing-reference potential may be greater than zero. The current recommended bias setting for example in the S+4ETO sensor is +300mV.
Therefore the maximum theoretical sensor voltage for biased sensors is 1.35V. However counter electrodes in practice do not polarise as far as hydrogen evolution, therefore it is true to say that in practice even biased sensor voltages are normally less than 1.2V.

2.3 Maximum values of open circuit voltages

The maximum possible sensor voltage is given by the NERNST equation for the electrochemical reactions at the sensing and reference electrodes.

The reference electrode is essentially the oxygen electrode reaction:

$$O_2 + 4H^+ + 4e \rightarrow 2H_2O$$

This reaction is irreversible and the true Nernst potential is never observed, even on very active catalysts like platinum. The maximum potential observed on DD-Scientific reference electrodes is about 1.05V on the normal N.H.E (normal hydrogen electrode scale). It is true to say in some sensors lower potential references are used and this is taken into account when deriving the figures below:

$CO + H_2O \rightarrow CO_2 + 2H^+ + 2e$	1.25V
$SO_2 + H_2O \rightarrow SO_3 + 2H^+ + 2e$	0.75V
$H_2S + 3H_2O \rightarrow SO_3 + 8H^+ + 8e$	0.76V
$H_2 \rightarrow 2H^+ + 2e$	1.05V
$NO + H_2O \rightarrow NO_2 + 2H^+ + 2e$	0.37V
$NO_2 + 2H^+ + 2e \rightarrow NO + H_2O$	0.20V

From the above equations the maximum open circuit voltage will be less than 1.2V in all cases except CO. The theoretical maximum for CO is 1.25V, which corresponds to 100% CO. At lower concentrations the voltage will be reduced by 60mV/decade e.g. 10% CO giving 1.19V.

However in practice the above estimates of maximum possible open circuit voltage are highly unlikely to be achieved because of the following reasons:

The presence of oxygen at the sensing electrode creates a mixed potential which reduces the sensing-reference potential difference.

In the open circuit condition, reactant gas can diffuse to the reference and counter electrodes causing an equalization of potential differences.

Most of the reactions, particularly carbon monoxide are irreversible, so the full NERNST potentials are never realized.

Testing at DD-Scientific show that the reasons stated above are factors which do indeed limit the open circuit voltages substantially even with high concentration exposures. An example of this is when a CO sensor was exposed to 20% CO and 0.35V was recorded. These potentials vary according to the logarithm of the gas concentration, open circuit voltages will not vary greatly at higher concentrations.

Although it is clearly theoretically possible to generate more than 1.2V in an open circuit situation, in practice this is never observed.

2.4 Maximum current on short circuit from an open circuit condition

Peak short circuit currents will be a function of the open circuit potential developed during the open circuit. The maximum values measured in tests at DD-Scientific in 20% CO, was 0.47 amps from an open circuit potential of 0.75V. Maximum possible potential is 1.2V so therefore we can deduce that the MAXIMUM POSSIBLE short circuit current would be 1 amp.

2.5 Below is a summary on Toxic Gas Sensors:

Maximum current possible in normal operation = 0.05 Amps
Maximum cell voltage possible in normal operation = 1.2 Volts
Maximum open circuit voltage possible = 1.2 Volts
Maximum peak short circuit current possible = 1 Amp

3.0 Oxygen Sensors

3.1 Currents and voltages generated under normal operation at 20°C

Current Outputs

Below are current outputs in dry, ambient air:

S+4OX = 0.4 mA
S+7OX = 0.4 mA

The above sensors are non-linear and shows increasing sensitivity at oxygen concentrations above normal ambient air levels of 21%. Maximum currents of 10 mA are observed in pure oxygen.

Open circuit voltages

Open circuit voltages over the range 10-100% O_2 were measured to be less then 0.8V for all oxygen sensors in tests carried out. Therefore there is no known way that the open circuit voltage could be greater than 0.9V.

3.2 Maximum Current on short circuit from an open circuit condition.

Peak current values of 200mA maximum were observed on oxygen sensors over the concentration range 10 to 100% O2. The peaks decay very rapidly within a few seconds to the normal operating currents as oxygen within the cell is consumed and further ingress is controlled by the capillary diffusion barrier.

Peak short circuit currents are primarily a function of the open circuit voltage generated and are very similar for all types of oxygen sensors. Some variations might be expected on testing larger sample sizes, but it is unlikely that currents would ever reach significantly greater values than 200mA and a reasonably safe limit to quote would be = 500mA.

3.3 Below is a summary on Oxygen Sensors:

Maximum current in normal operation (pure O_2) = 0.01 Amps
Maximum open circuit voltage (10 to 100% O_2) = 0.9 Volts
Maximum peak short circuit current (10 to 100% O_2) = 0.5 Amps