Pewatron Application Note PAN-04: Zirconia oxygen gas sensor – influence of the humidity and the use of the sensor as a humidity sensor

The FCX zirconia oxygen sensor is calibrated using dry mixtures of O_2/N_2 gas and normal air. In most applications there will be a certain humidity in the gas to be analyzed (for instance in CO_2 incubators, where relative humidity levels can vary between 0 and 100 %) or the application draw gas from the ambient air, which contain varying amounts of humidity. In this application note, we discuss how to correct for humidity in calculating the true oxygen partial pressure and we present an interesting application, where oxygen concentration measurements can be combined with a measurement of the humidity level in the gas.

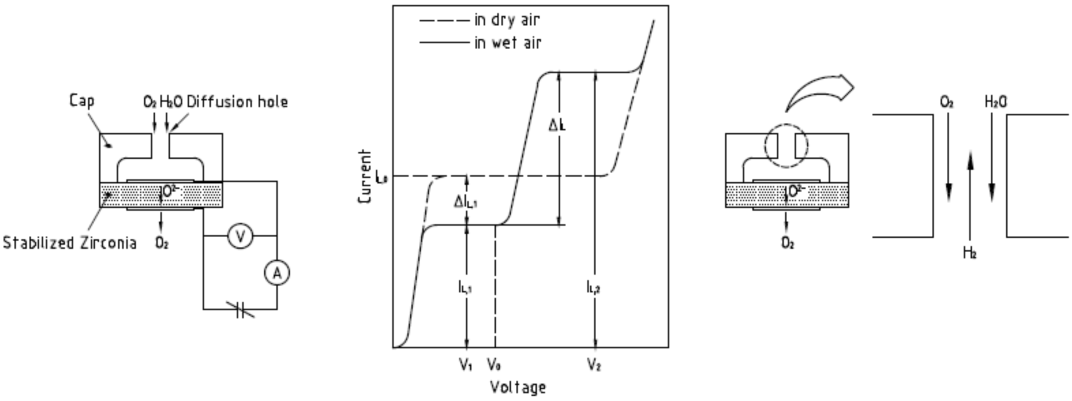

Fig. 1. The principle of operation for the FCX-UC sensor in humid air

Zirconium oxide (with proper dopant elements; zirconia), and when heated > 350 °C, is penetrable for oxygen ions. The FCX oxygen sensor series has its working point at 450°C. A voltage applied to the oxygen sensing element, pumps the oxygen out of a closed inner chamber. At a constant gas pressure, the quantity of oxygen pumped out is equal to the quantity of oxygen molecules diffusing in through a small capillary hole. This equilibrium is independent of the voltage applied between the electrodes within a certain range from ~0.7 to ~2.0V (Fig. 1.). The measurement current is proportional to the quantity of oxygen molecules pumped away and thus the oxygen partial pressure. This theory applies for dry gases only and gases containing only oxygen and nitrogen (balance). Gases containing humidity (normal air as an example) change the behavior of the oxygen pump slightly; in Fig. 1 two regions in the equilibrium current-voltage section of the I-V curve is identified. In the first region (~0.7-1.5 V), the output signal decreases with increasing humidity and constant oxygen partial pressure (Fig. 1). In the second region (~1.5-2.0 V), the output signal increases with increasing humidity and constant oxygen partial pressure (Fig. 1). The physical explanation of this behavior is relatively straightforward to explain: above a certain sensor voltage the water content in the gas mixture is electrolytically split into hydrogen and oxygen, which then give an excess current directly proportional to the humidity content. Below a certain sensor voltage the water vapor add to the total pressure, which is constant. As a result, the apparent oxygen concentration seem lower, because the oxygen partial pressure decrease.

The partial pressure is defined as the pressure of a single gas components (N_2, O_2, H_2O, CO_2,…) in a mixture of gases. The total pressure (p_t) of a mixture of ideal gases is equal to the sum of the partial pressures (p_i) of the gases in the mixture (Dalton's law). The gas mixture has a total number of particles (n_t), which is the sum of particles (n_i) for the individual gases in the system. For means of simplicity, and with a sufficiently good accuracy, normal air is considered an ideal gas, and the number of particles from the gas constituents in normal air can be calculated from the volumetric content (%Vol.) of gases in normal air. Normal dry air (at standard conditions) consists of nitrogen (78.09 %Vol.), oxygen (20.95 %Vol.), argon (0.927 %Vol.) and carbon dioxide (0.033 %Vol.).

The atmospheric pressure at sea level and under standard conditions is 101.325 kPa. The oxygen partial pressure is then (20.95 %Vol.)/(100 %Vol.)*101.325 kPa = 21.228 kPa, but only when the atmosphere is dry (RH = 0 %). If humidity (i.e. water molecules) is present, a certain proportion of the total pressure is taken up by water vapor pressure. Humidity in air lower the oxygen partial pressure, and it thus important to be able to correct for humidity and ambient temperature for oxygen gas sensors measuring the partial pressure of oxygen. The correction for humidity effects is relative straight forward to calculate using the following equations:

O_2 (%Vol.) = 20.95% * (1-(p_{H20}/p_t)), where

p_{H20} = RH(%)*$p_{H20,max}$(T_a)/100.

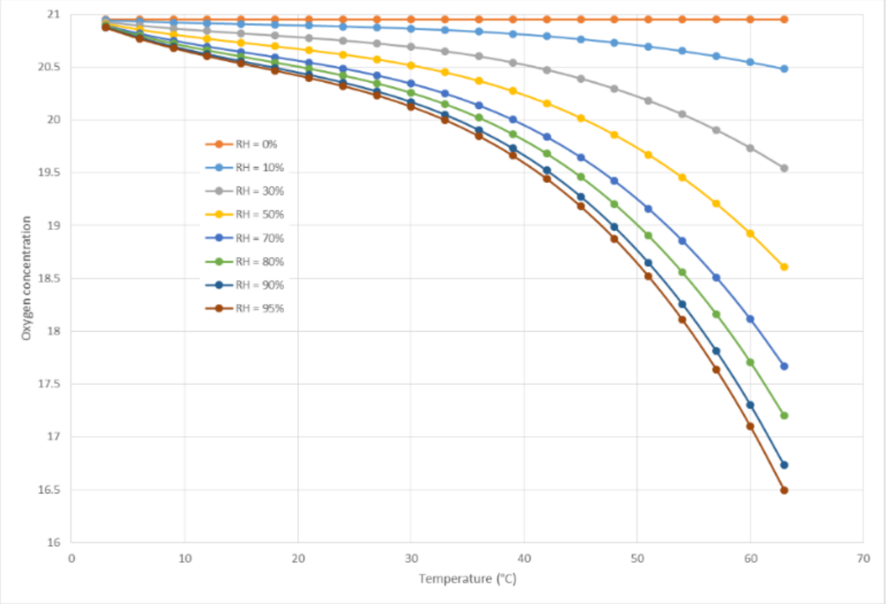

Fig. 2. Oxygen concentration as a function of temperature and humidity

The maximum water vapor pressure, $p_{H20,max}$, is very dependent on the ambient temperature, T_a. As an example, at 20°C, the air can have a maximum content of 2.337 kPa water vapor pressure, but at 50°C the maximum content is almost a factor 5 higher, namely 12.338 kPa. The impact on the oxygen concentration by a relative humidity of 50% is for both cases significant; @ 20°C/50 %RH/101.325 kPa, O_2 decreases to ~20.70 %Vol and @ 50°C/50 %RH/101.325 kPa, O_2 decreases to 19.67 %Vol. The FCX zirconia sensor, biased with a sensor voltage below ~1.5 V, will output these oxygen sensor concentrations, because the sensor biased in the voltage range from 0.7 V to 1.5 V measures the oxygen partial pressure. Fig. 2 above show the oxygen partial pressure as a function of the temperature for various levels of the relative humidity and assuming normal air at standard conditions.

The oxygen sensor, biased above 1.5 V (but below ~2.0 V), will output the sum of the oxygen partial pressure and the water partial pressure, because water is split into hydrogen and oxygen at the surface of the heated sensor.

The FCX sensor is a very good and stable humidity sensor, and it has many advantages over normal humidity sensors. One of the most obvious advantages of the FCX humidity is the ability to work at high temperatures, but also the accuracy and the resolution of the sensor is better or comparable to state-of-the-art capacitive humidity sensors.

There are two approaches that both work equally well and in order to determine partial pressure of water and oxygen in a given application. One approach measures the difference in current, ΔI_L, between the oxygen partial pressure reduction region (< 1.5 V) and the excess oxygen generation region (> 1.5 V). The other approach measures only in the excess oxygen generation region (> 1.5V). In the first case, the difference in current is

$$\Delta I_L \propto pH_{2}0 \frac{ln(1-pO_2/pt)}{p_{O_2}/pt}$$

and in the latter case the measured current is

$$I_{L_2} \propto \left(1+\frac{p_{H_20}}{2pO_2}\right) * ln(1-\frac{p_{O_2}}{p_t})$$

In both cases, an iteration process is needed to determine the oxygen partial pressure and the water partial pressure, assuming that both are varied in the process.

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