The Impact of Humidity

Scope

Discusses how zirconia oxygen sensors are impacted by humidity with respect to the signal and lifetime.

1 Factors Impacting Oxygen Levels and Sensor Signal

Oxygen levels can vary due to humidity just like any other change of composition within the analyte. Measured oxygen levels can additionally vary due to a multitude of physical reasons:

- Water splitting at the hot electrode
- Oxygen consumption at the hot electrode (combustion)
- Effects impacting diffusion
- Heat transfer – hot/cold gases and gases with different heat capacity or thermal conductivity
- Other effects

Additionally, condensation can impact the sensors performance or even cause damage.

In this document, let us focus on humidity – a common factor that needs to be considered in many applications.

1.1 The Impact of Humidity on the Volumetric Composition of Ambient Air

The oxygen concentration is naturally dependent on the water vapour content and contributes to deviations from the expected 20.9 vol%[1].

Dalton's law (law of partial pressures)

The total pressure p_{total} exerted by the mixture of non-reactive gases is equal to the sum of the partial pressures p_i of individual gases.

$$p_{total} = p_{bar}\,(h) = \sum_{i=1}^{k} p_i$$

$$p_i = \frac{[X_i]}{100} \cdot p_{bar}\,(h)$$

$[X_i]$	Mole fraction of gas i in mol%
p_i	Partial pressure of gas i
$p_{bar}\,(h)$	Barometric pressure (Vienna, 160m ASL: p_{bar} ~ 990 mbar)

Dry air is made up mostly of nitrogen (~ 78.084% by volume) and oxygen (~ 20.942%), with argon contributing another 0.934%. The remainder consists of small traces of other gases.

Water vapour isn't included in these values, because its amount varies a lot with the environment—on average it makes up around 0.4%, but it can range anywhere from 0% to 4%. When the air becomes

[1] In this document, all gas composition percentages (%) are referring to vol%, unless otherwise stated.

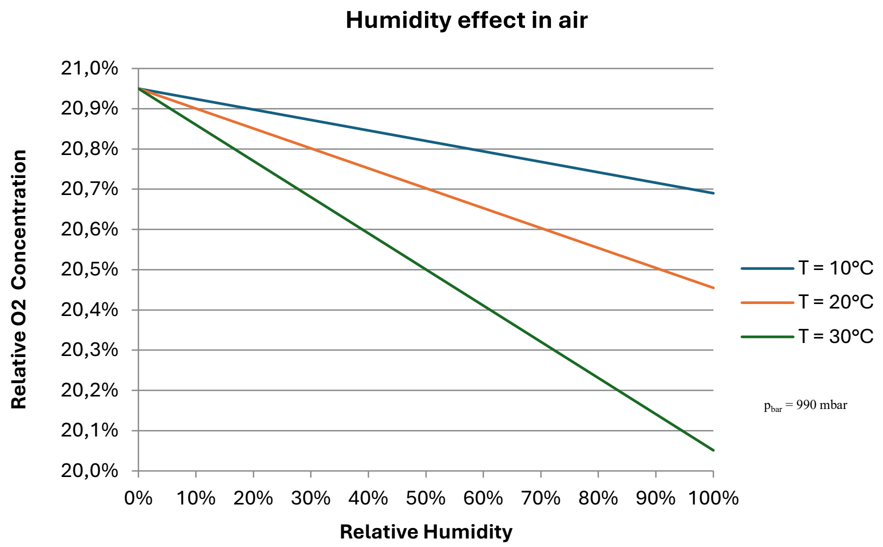
humid, the water vapour adds its own partial pressure and effectively pushes out some of the surrounding gases. As a result, the *relative* amount of oxygen in humid air decreases.

The amount of water vapour the air can hold depends directly on the temperature: warmer air supports higher saturated vapour pressure, which in turn increases how much water vapour can be present.

$$[O_{2\,humid}] = [O_{2\,dry}] \cdot \frac{p_{bar} - p_d}{p_{bar}}$$

$$p_d = \frac{\varphi}{100} \cdot p_s(T)$$

p_d	Water vapour pressure [mbar]
φ	Relative humidity in %
$p_s(T)$	Temperature-dependent saturated vapour pressure [mbar]
$[O_{2\,humid}]$	Oxygen content of humid in %
$[O_{2\,dry}]$	Height independent oxygen content of dry air = 20.942 %



1.2 H_2O interaction with the Sensor

Especially in low oxygen environments water splitting can occur, increasing the measured oxygen. In most applications this effect becomes apparent at O_2 levels below ~1% and overestimates the oxygen level by varying degrees.

Let us add some numbers to illustrate a high humidity environment at 25°C, 90% RH and an artificially increased electrode bias voltage of 1V to promote water splitting:

- For an 2% sensor at 1V electrode bias voltage the effect becomes apparent at ~0.2% O_2
    - At an O_2 level of 0.1% the sensor shows 0,12%
- A 25% sensor in the same conditions would read 0.4%. Despite the high humidity, the reading is very close to the specified maximum of 0.35% (=lower range limit of 0.1% and a maximum deviation of 0.25%).

Thus, understanding the effect of humidity on the O_2 measurement is vital in applications, with elevated humidity and low levels of oxygen.

1.2.1 Dealing with humidity

These effects can be mitigated by:

- Reducing humidity levels
- Adjusting the bias voltage applied to the electrodes
  - the rate of water splitting is dependent on the bias voltage applied. Reducing the bias voltage will reduce the water splitting, but it might negatively affect the lifetime stability at full scale readings. So, selection of the bias voltage is always a compromise between optimal performance at low O2-levels and high O2-levels.
- Employing Sensores optimised design ("e" variant, e.g.: D0**e**010) with improved performance in humid low O_2 environments

2 Condensation

The operating temperature of zirconia sensors presents another challenge when it comes to condensation. Should a sensor get wet while its cold, the moisture would evaporate rapidly and can cause the sensor chip damage. If a sensor chip should encounter water while it is at operating temperature, the thermal stress due to rapid cooling is also likely to damage the sensor. Additionally, condensate mobilizes potential residue and contaminants on surfaces, which can further impact the sensors performance.

Thus, it is important to keep the sensor dry by keeping the sensor chip heated to above 100°C whenever conditions are such that condensation can be expected.

2.1 Applications with condensation risks

2.1.1 Outdoor applications

Due to the condensations risk, the sensor is not an optimal choice for outdoor applications. If a permanent operation (heating) of the sensor can be ensured outdoor conditions might be feasible.

2.1.2 O2-Measurements in steam ovens

It is not recommended to use the sensor in steam oven applications. For kitchen ovens there are further condensation risk of other volatile substances, e.g. oil/fat.
In >90% steam water splitting might occur also above 1% O2.

2.1.3 refrigerated applications

As the power dissipation of the sensor is relatively low (1.5W) it might be considered for the use in refrigerated applications. Also, in this application condensation could be prevented by heating the sensors. This is important under conditions where warm humid air from outside the refrigerated application might rush in.

3 Summary

The presence of humidity must be considered for accurate oxygen measurement as it:

- Alters the relative composition of the gas mixture
  - Resolution: Apply Dalton's law
- At low O_2 concentrations, H_2O splitting can increase the oxygen signal
  - Resolution
    - Reduce humidity levels, if possible
    - Optimise/decrease electrode bias voltage
    - Use the dedicated "e" sensor design to minimise effect
- Can potentially damage the sensor, when condensation occurs onto the cold sensor
  - Resolutions:
    - Avoid condensation whenever possible
    - When operating under the risk of condensation, keep the sensor heated
      - If necessary, the heating power can be reduced, if the sensor is kept above ~100°C

3.1 Note on combustible and reactive gases

Combustible gases like CH_4 or CO consume oxygen, reducing the oxygen readout. Also, a passivation layer can start forming on the electrode, reducing the sensors lifetime. Furthermore, chemically aggressive gases (like HF, HCl, F_2...) can also damage the sensor. See appl. note 7 "Reactive Gases".

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