MEM2 Application Note Oxygen Sensor

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1) Sensor Principle

Electrochemical Gas Sensors in General

Electrochemical sensors operate by reacting with the analyte and producing an electrical signal proportional to the analyte concentration. Electrochemical gas sensors are generally amperometric sensors, generating a current that is linearly proportional to the gas concentration. The principle behind amperometric sensors is the measurement of the current-potential relationship in an electrochemical cell where equilibrium is not established. The current is quantitatively related to the rate of the electrolytic process at the sensing electrode (also known as working electrode) where the reference electrode's potential is constant. At the counter electrode a counter-reaction takes place and balances out the reaction of the sensing electrode, thus completing the electrical circuit. The ionic current between the counter and sensing electrode is transported by the electrolyte inside the sensor body, whereas the current path between is provided by wires which are terminated with pin connectors.

Working Principle of the Membrapor Oxygen Sensor

Oxygen diffuses through a capillary to reach the surface of the sensing electrode. With this approach the amount of gas entering the sensor is controlled by diffusion.

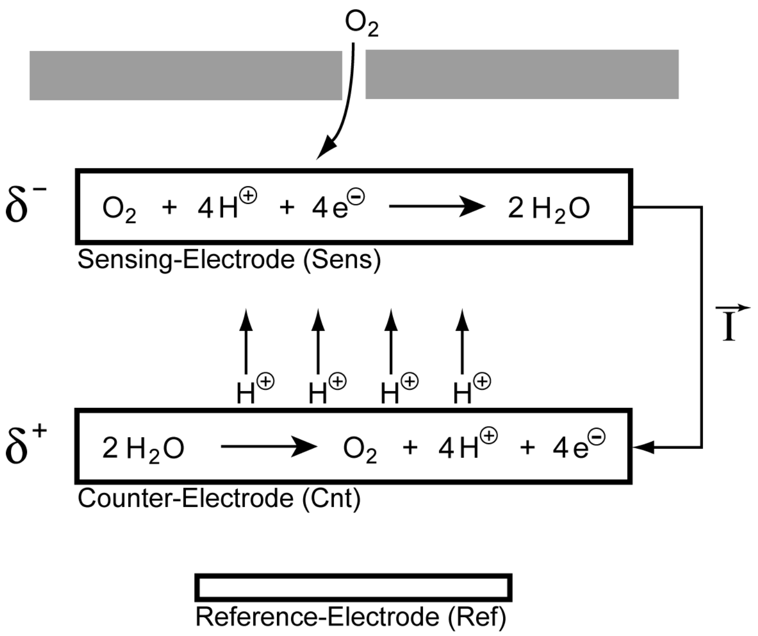


Figure 1 Working principle of the oxygen sensor

The oxygen reaching the sensing electrode is reduced, i.e. it consumes electrons which results in a current. The counter electrode balances the reaction of the sensing electrode by oxidizing water. Thereby protons are produced at the counter electrode. These migrate through the electrolyte towards the sensing electrode. A potentiostatic circuit maintains the potential of the sensing electrode at -600 mV with respect to the reference electrode potential. This negative bias potential is necessary to operate this amperometric fuel cell. In opposite to other biased sensors, the Membrapor oxygen sensor is stabilized within a few minutes when the circuitry is switched on.

In opposite to galvanic O2-sensors this type has no consumable parts, nor does change anything inside with time. Surrounding oxygen has no impact on storage life and the sensor is RoHS compliant in opposite to lead-based sensors.

2) Characteristics of Membrapor Oxygen Sensor

- **Lifetime not limited**
  In opposite to galvanic O2-sensors this type has no consumable parts, nor does change anything inside with time
- **Easy storage**
  Storage is unproblematic in opposite to sensors with sacrificial anode
- **RoHS compliant**
  This sensor does not contain any toxic metals in opposite to lead-based sensors
- **Reliable**
  This sensor is based on the same technology as Membrapor`s sensors for toxic gases: High quality gas sensors based on many years of experience.

Performance details are given in the data sheet.

3) Output Signal

Refer to Application Note MEM4 for a detailed derivation of the content below.

Linear Approximation in normal use

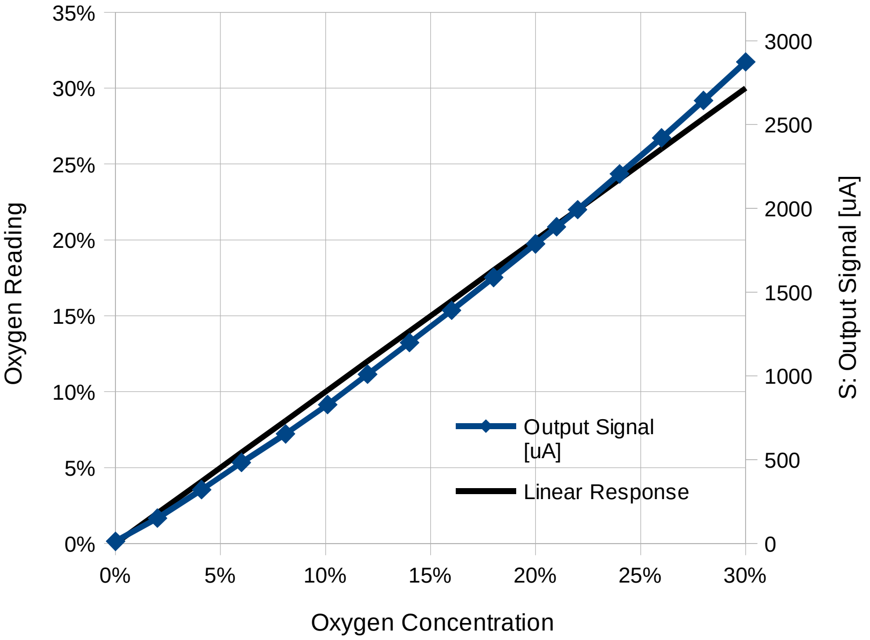
The Membrapor Oxygen Sensor is based on capillary-type diffusion (normal diffusion). Thus, the output signal of the O2-sensor follows the relationship:

$$S = K \ln \frac{1}{(1-X)}$$

where:

S: Output signal
X: Fractional O_2 concentration
K: Constant of the sensor
$\ln$: natural logarithm function (base e)
(written also as $\log_e$)

Output Signal vs Oxygen Concentration



The graph shows the output signal of a sensor compared to a strictly linear response. Note the intersection at the calibration point, in this case 20.9% O_2 (ambient air). The strongest deviation is observed at 10% O2 where the sensor reading is 9.2%. For many applications such a deviation is insignificant and a linear relationship can be used to convert the sensor signal to the concentration reading:

$$X = \frac{S}{a}$$

where:

X: Oxygen concentration [%]
S: Output signal [μA]
a: Sensitivity of the sensor [μA / %]

Exact Calculation for Best Accuracy

To obtain highly accurate readings over a large measurement range, the following equation should be used:

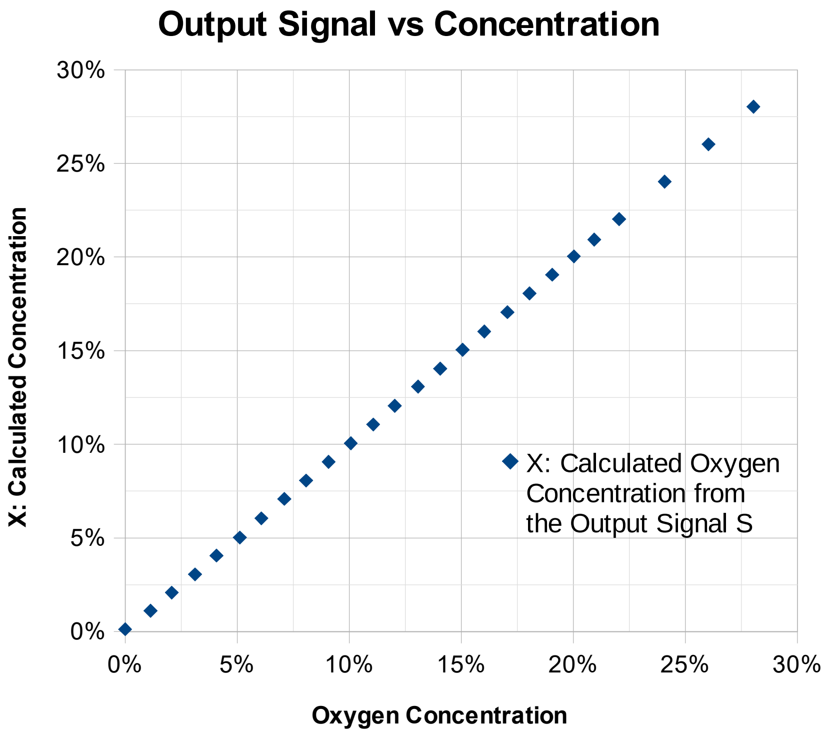
$$X = 1 - \exp\left(\frac{-S}{K}\right)$$

where:

X: Fractional O_2 concentration
S: Output signal
K: Constant to be determined
$\exp$: natural exponential function (base e)

The constant K can be calculated from the value S at a calibration point X. The value of K is around 7600 ± 1000 [1/µA], if the output signal is in µA.

The graph below shows the resulting X based on the output signal S of the PCB from Membrapor, converted to µA. The signals were obtained with stepwise increased oxygen concentrations.



The obtained values based on the formula above are very accurate. With this method the reading error in oxygen concentration is within ±0.1%.

For questions and assistance contact the technical support team at MEMBRAPOR.

4) Designing a Potentiostatic Circuit for the Oxygen Sensor

To operate an electrochemical sensor a control circuitry is required, referred to as the potentiostatic circuit. For a 3-electrode sensor the main purpose is to maintain a voltage between the reference electrode (Ref) and the sensing electrode (Sens) to control the electrochemical reaction and to deliver an output signal proportional to the current produced by the sensor. The potential on the counter electrode (Cnt) is not important, so long as the circuit can provide sufficient voltage and current to maintain the correct potential of the sensing electrode.

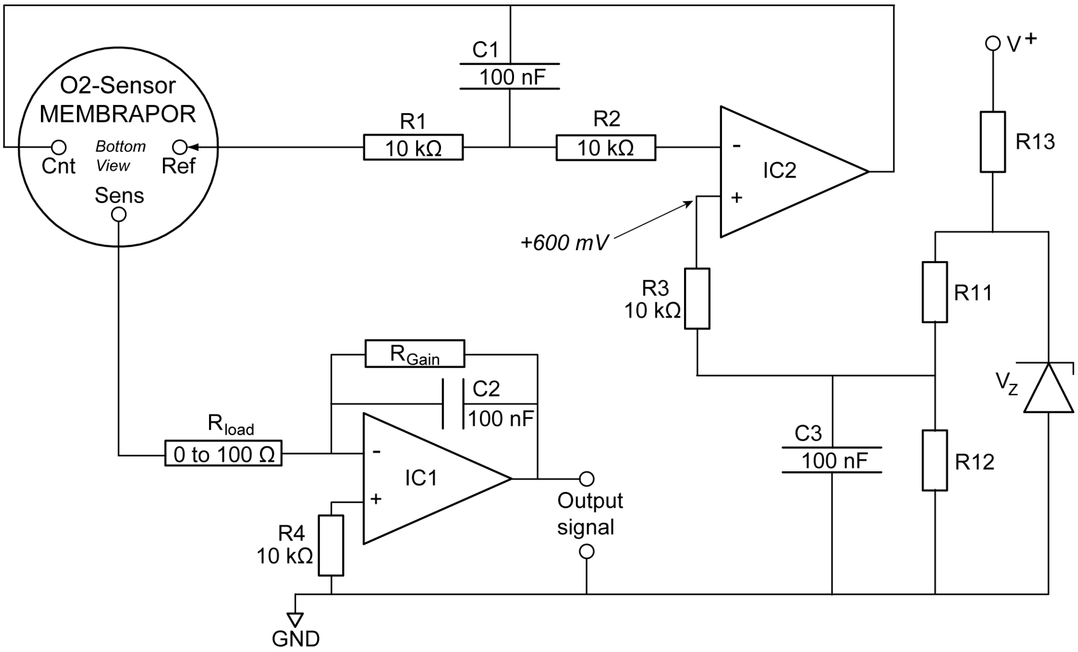


Figure 2 Schematic diagram of the electronic circuit for the O2-sensor

The resistors R11, R12, R13 have to be chosen in the way that a VSET of +600 mV is supplied at the positive input of the operational amplifier IC2. The potential of the sensing electrode is held at 0 V by the biasing effect of the output circuit resulting in a -600 mV bias between Sens and Ref.

The reference voltage of the virtual earth should be chosen appropriate to allow enough voltage swing of the counter electrode. The maximum voltage between counter and sensing is 1.3 V. For example if the supply voltage is 2.5 V and the corresponding maximum voltage of the IC2 is 2.0 V, then the reference voltage must be below 0.7 V for the virtual earth.

The measuring circuit for the electrochemical sensor is a single stage op amp IC1 in a transimpedance configuration. The sensor current is reflected across R_{GAIN}, generating an output voltage relative to the virtual earth GND. C2 reduces high frequency noise. The recommended value of the load resistor (R_{load} =10 Ohm) is a compromise between fastest response time and best signal-to-noise ratio. The input offset voltage of the op amp IC1 will add to the sensor bias voltage (as the sensing electrode will be offset from 0V) so the input offset should be kept low. An op amp should be chosen with low input offset voltage temperature drift, to not affect the bias voltage when temperature changes.

The control operation amplifier IC2 provides the current to the counter electrode to balance the current required by the sensing electrode. Because the counter is oxidizing, it sinks a current into IC2. Therefore, IC2 needs to have an adequate current sinking capability. The inverting input into IC2 is connected to the reference electrode and must not draw any significant current from the reference electrode. An operation amplifier with an input bias current of less than 5nA is recommended.

5) Connecting the Sensor to the Circuit

Never solder connectors directly onto the pins of the sensor. Connection should be made via a PCB mounting socket.

WARNING: SOLDERING TO PINS WILL RENDER YOUR WARRANTY VOID.

6) Usage of the Sensor

Sensor must not be exposed to temperature, humidity and pressure outside the range quoted in the sensor data sheet.

Sensor should not be exposed to organic vapour, which may influence the baseline or even cause physical damage to the body of the sensor.

Electrochemical gas sensors are classed as non-dangerous and may be transported without special packaging or labelling. Although, you are advised to check any local regulations.

7) Intrinsic Safety Considerations

The O2/M-100 is a three electrode cell which produces small currents and voltages and is not able to store large quantities of energy.

The current of the sensor increases linearly over the recommended operating range of the oxygen concentration and is measured as the sensor output:

sensor sensitivity [μA/%] x O_2 concentration [%] = output signal [μA]

Maximum current in normal operation (0 - 30% O2): < 4 mA

Maximum voltage in normal operation (0 - 30% O2): < 1.2 V

Maximum current at any concentration (0 - 100% O2): < 20 mA

Maximum voltage at any concentration (0 - 100% O2): < 1.3 V

Note:

IEC 60079 – 11, 5.6 Simple apparatus:

“The following apparatus shall be considered to be simple apparatus: Sources of generated energy, which do not generate more than 1.5V, 100 mA and 25mW.”

8) Product Safety

The Membrapor Oxygen Sensor is not considered a chemical hazard in normal use.

Should the housing be damaged, the electrolyte inside the sensor may leak out. Exposure to the sensor electrolyte, which is diluted sulfuric acid, is the only component that may potentially prove hazardous to health. In the event of skin contact, rinse with plenty of water and seek medical advice.

9) Storage

Sensors should be stored in their original packaging below 30 °C and 90% RH. Surrounding oxygen has no impact on storage life in opposite to sensors with a sacrificial anode. Do not store sensors together with organic solvents or flammable liquids.