TELEDYNE ELECTRONIC TECHNOLOGIES
Analytical Instruments

Medical Oxygen Sensors

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Medical Oxygen Sensors and Applications

Of all gases, oxygen plays a unique part in human existence. Without it, life as we know it could not exist. The nature and measurement of oxygen has, therefore, always been an important challenge to the designers of oxygen measuring equipment. Teledyne Analytical instrument (TAI) was the first to patent and produce high quality galvanic electrochemical oxygen sensors for use in medical applications. Over the years our specifications and assembly techniques have improved dramatically and we presently are the largest supplier of these quality sensors throughout the world, not just in medical oxygen measurements but in industrial and nuclear applications, as well.

TAI's Micro-fuel Cell (MFC) is an electrochemical transducer. A transducer is a device that converts one form of energy to another; for example, a loudspeaker is a transducer that converts electrical energy into mechanical energy (sound). A microphone is a transducer that is the opposite of this; mechanical energy is converted to electrical energy. The most common electrochemical transducer is a battery, it transforms chemical energy into electrical energy. A fuel cell is another electrochemical transducer. Unlike the battery, which stores its energy internally, the fuel cell stores its energy externally.

The Micro-fuel, then, is a fuel cell where oxygen, entering the cell from the gas mixture surrounding the device, supplies the missing ingredient for the electrochemical system, and produces a current that is proportional to the concentration of oxygen in that gas mixture. The sensing (cathodic) reaction is as follows:

$$4e^- + O_2 + 2H_2O = 4OH^-$$

Simultaneously and upon demand from the above half-reaction, the Lead anode is oxidized to lead oxide:

$$Pb + 2OH^- = PbO + H_2O + 2e^-$$

The sum of the above two half-reactions is:

$$O_2 + 2Pb = 2PbO$$

There is absolutely no maintenance associated with the use of the Micro-fuel Cells. The output signals extremely stable. It is not uncommon for a cell (installed in one of our instruments) at a constant oxygen concentration, to produce an output that is within ±1% oxygen for several weeks. The MFC was designed to be insensitive to shock, vibration and position. The cell can be accidentally dropped with normally no adverse effects. It can be mounted in virtually any position without changing its sensitivity. Since sampling of oxygen is diffusion controlled the rate at which the sample gas flows over the sensing surface is not critical (providing no significant back pressure is produced. Most TAI medical sensors can be used in anesthesia applications where N2O can be a problem with some electrochemical cells.

The following paragraphs deal with special medical environmental effects that should be understood before utilizing membrane clad electrochemical oxygen sensors for making oxygen measurements:

<u>Pressure</u>: Virtually all gas sensors and monitors measure the partial pressure, not the percentage, of the gas that they sense. The only time that these instruments can accurately read percentages is when the total pressure does not vary over time between calibration and use. This is why it is suggested that sensor be calibrated at regular intervals. It is recommended that the sensor, in its unit, be calibrated prior to each use or every 8 hours, whichever occurs first.

When the sensor is connected to a ventilator circuit, the alternating "breathing" pressure cycles generated by the ventilator will be sensed as an increase in the oxygen percentage (especially if the sensor is fast enough to sense the changes). In reality, the percentage of oxygen in the gas mixture is not changing; it is the total pressure that is increasing, producing a corresponding increase in the partial pressure of oxygen. A hundred-centimeter water pressure pulse will produce a .11 atmosphere, or an 11% increase in the total, and therefore partial pressure, of oxygen. Assuming that the sensor is fast enough to track this pressure pulse, an unpressurized reading of 50% oxygen will increase to 55.3% if the sensor is subjected to a pressure cycle whose amplitude is 100 cm H_2O. The reading will rise proportionally less for smaller pressures.

<u>Humidity</u>: Humidity does not directly affect the accuracy of the sensor's measurement. However, when a nebulizer or other device is used to increase moisture levels in gas mixtures, the moisture (or water vapor) actually dilutes the mixture. This dilution effect decreases the oxygen concentration. For example, if an 80% oxygen gas mixture is humidified to saturation at room temperature, the resulting gas mixture will contain only 77.5% oxygen. Your TAI oxygen sensor accurately measures the decrease in the oxygen concentration due to the dilution effects of moisture added to gas mixture.

Normally adding moisture to the gas mixtures being fed to patients is not problem, but as with all membrane clad oxygen sensors, <u>excessive</u> condensation on the sensing surface will block the diffusion of oxygen to the sensor, even when the sensing surface is protected by a hydrophobic cover. We recommend installing the sensor on the dry side of the breathing circuit whenever prolonged exposure to 100% relative humidity (especially when using heated type humidifiers) is to be encountered.

When excessive condensate occludes the sensing surface, the oxygen sensor should be removed and the water shaken off and the sensor allowed to air dry. Passing dry gas (e.g. 100% oxygen) over the sensing surface can hasten the drying operation.

<u>Temperature</u>: Most TAI medical oxygen sensors are internally compensated for ambient temperature changes in the range of 0–40°C (32–106°F). Since the thermistor that compensates for these changes is located in the rear of the sensor assembly, it is important that gas mixtures, flowing over the front of the sensor, be at room

temperature. Reading errors may occur if hot gases from a heated humidifier are directed past over the sensing surface of a sensor teed into a breathing circuit.

A small thermal tracking error may be encountered in application areas where the entire sensor assembly is placed in the gas mixture to be analyzed (e.g., incubators). No adjustments should be made during this period (about 1 to 2 hours), since this error will be eliminated when both the thermistor and sensing electrode have had sufficient time to come to thermal equilibrium.

Discrepancy in Readings: Medical oxygen sensors should not be used as a primary monitoring device. The sensor is intended to be used as a secondary oxygen monitor, meaning that it is intended to verify the accuracy and check the oxygen concentration leaving another oxygen mixing device or primary life support system (i.e., a blender or anesthesia machine). Whenever there is a significant difference in the oxygen readings between the primary and secondary monitors, the discrepancy must be resolved immediately. The information obtained from the oxygen sensor and unit should never be used to make adjustments to the primary life-support system, but should only be used as an indication that the primary device may require service and/or calibration. The oxygen monitors batteries should be checked and replaced, if necessary. The monitor should be recalibrated (preferably in 100% oxygen and then checked in air) to verify that the oxygen monitor is working properly.

Sensor Life: The life expectancy numbers listed in the Product Specification table are calculated from a theoretical calculation assuming 70% anode efficiency. Anode efficiency test data was collected by analyzing cells with their anodes completely spent. Normally, data of this type shows anode efficiencies between 75 and 85% (i.e. this percentage of the lead, placed in the cell during manufacture, is utilized in sensing oxygen over the life of the cell).

The Average Expected Life specification expresses the expected life of each sensor in terms of "months in air". Some sensor manufacturers express sensor life in %-hours. For comparison purposes and to convert to %-hours from "months of life in air", use the following relationship:

$$\text{\%-Hours} = (\text{months of life in air}) \times (1.5 \times 10^4)$$

By way of example: the average expected life in the Product Specification table for the R-15 Oxygen Sensor is 36 months in air. To convert this to %-hours, substitute in the above formula:

$$\text{\%-Hours} = (36) \times (1.5 \times 10^4) = 540{,}000 \text{ \%-hrs}$$