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Teledyne Oxygen Sensors Seminar Notes

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TELEDYNE OXYGEN SEMINAR

The Gas Laws

Boyles Law.

"The absolute pressure is inversely proportional to the volume provided that the temperature is constant."

$P1 \times V1 = P2 \times V2$

The critical factor for this equation to work is temperature as temperature is assumed to be constant.

Daltons Law.

"The total pressure is the sum of the pressures which the quantity present of each gas would exert if it alone occupied the vessel"

When the gas is air **P**total = **PO**xygen + **PN**itrogen

where Pt is the total pressure
PO is the partial pressure of Oxygen and
PN is the partial pressure of Nitrogen.
At the Standard pressure of 1 Bar in air **1 bar = 0.21 + 0.80**

If a gas contains 32% O2 and 68% Nitrogen the equation becomes **1 Bar = 0.32 + 0.68**

Henry's Law.

The amount of gas which dissolves in the liquid is directly proportional to the partial pressure of the gas adjoining it.

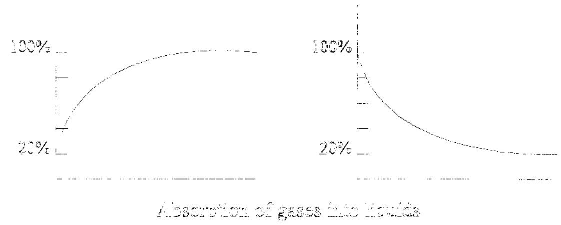


Fig 1 The absorption of gases into liquids.

Each of these gas laws plays a vital part in the mechanism of electrochemical galvanic fuel cells
All electrochemical sensors produce an output current directly proportional to the Partial Pressure of Oxygen

At STP the partial pressure of O2 is .209
At STP the percentage O2 present in air is 20.9%

It is important to ensure all Oxygen measurements are made at 1 Bar. Any container e.g. plastic bags or occluded Tee pieces must allow the gas to vent naturally into the atmosphere. Only when the restricted gas has reached equilibrium with the surrounding atmosphere of 1 Bar will the measurement be accurate.

The Galvanic Oxygen sensor

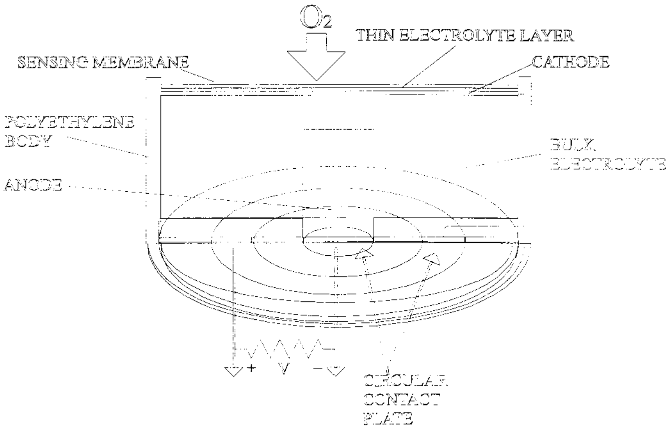


Fig 2 Simplified construction of a micro fuel cell

The basic constituents of a sensor consists of a lead anode a gold plated cathode with a solution of Potassium Hydroxide as an electrolyte.
The cathode is a convex metal disk plated with a noble metal e.g. gold, silver, platinum etc. with numerous perforations. It contains a small amount of electrolyte between the membrane and the cathode. This is to assure minimum internal resistance during the oxygen sensing reaction. It is essential that this portion of the electrolyte does not dry out or the membrane be allowed to contact the cathode directly.

The lead is oxidised into lead oxide and the reaction produces a small current between anode and cathode.
The rear of the sensor has another flexible membrane which is designed to accommodate internal volume changes that occur throughout the life of the sensor.
The sensing membrane is made of Teflon
The space between the two membranes is filled with an solution of potassium hydroxide .
The main sensor body is manufactured from high density polyethylene.

Galvanic oxygen sensors require no external battery to work. They consume Oxygen and produce a small electrical current.

Initially fuel cells were designed to produce electricity in space using Oxygen as a fuel and were used by NASA in the space program to power manned space vehicles.

The earliest micro fuel cell sensors produced a large current output of 1 milliamp at 100% oxygen and can drive an analogue meter direct.

The simplest Oxygen analyser employs no electronics but is simply a sensor and a 100 microAmps meter moving coil meter.

The sensor is made from several small parts each controlled to high standards . However no two sensors can be absolutely identical and therefore there will inevitably be small differences in outputs. These are canceled out in the monitor by using a calibration control

Sensor Linearity

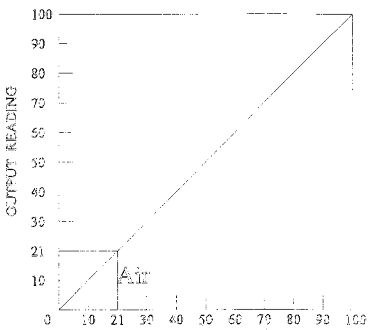


Fig 5 Sensor linearity. The sensor output is linear over its range

Temperature

The micro fuel cell sensor is temperature sensitive and increases its output by approximately 2.5% per degree Celsius. It therefore requires temperature compensation to keep it linear.

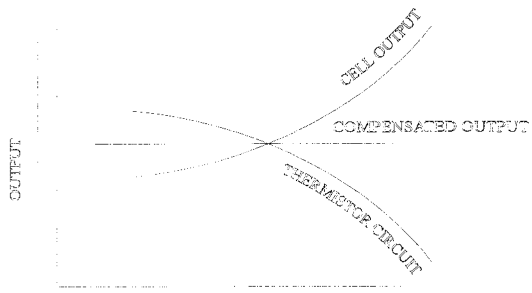


Fig 6 Temperature compensation

Fig 7 Thermistor circuits

Temperature compensation can either be built into the sensor, into a sensor holder. or a combination of sensor and measuring circuit. Any of these methods produces the same effect

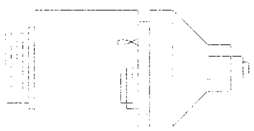


Fig 8a Sensor Holder

Fig 8b Inbuilt thermistor in sensor

The response of the temperature compensation circuit is designed to be exactly the opposite of the sensors response to temperature. With careful design the two effects cancel out.

It is assumed that the sensor and the temperature compensation components are always at the same temperature. For most applications and the accuracy required the assumption is correct. However if the gas is cold or hot a temperature gradient will exist across the sensor.

In sensors like the R-17 the temperature compensation circuit is located in the sensor immediately behind the socket.

Response time

The response time of sensors is defined as the time taken for the output of the sensor to reach 90% of the final reading on a step change.

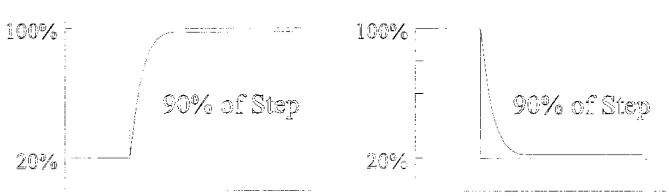


fig 9 Response to step change

Accuracy

There are two main components affecting the accuracy of a monitoring system

Temperature:
The thermistor network can achieve an accuracy better than +/- 5% in tracking error which in practical terms means that a temperature change of 5-10 degrees Celsius will produce a maximum error of +/- 1% of reading.

The method of display

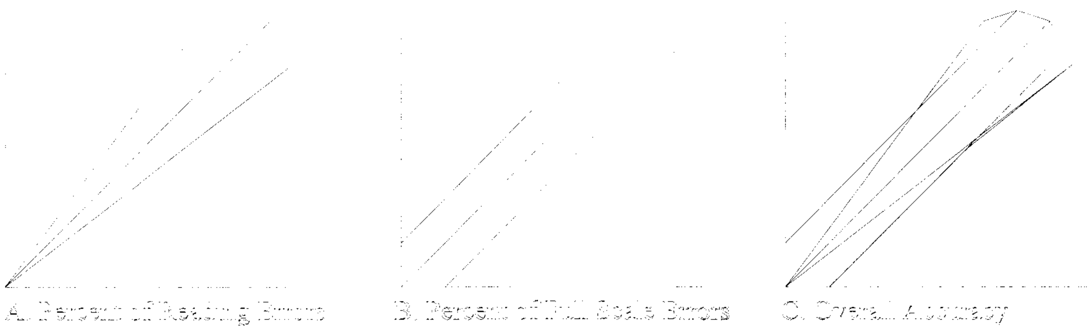


fig 10 Inaccuracies of measurement

Digital readouts
Digital readouts can easily achieve a resolution +/- 0.1% and the errors can be contained well within the resolution of the final digit.

Sensor life

The sensor life can be calculated as follows:

Life in months = Pb * K * 70% /I in 100% Oxygen (I = output current in Amps)
(Pb= Amount of lead)

K= 3.59 * 10 -4 (Proportionality constant)
70% = Anode efficiency.

As a rule sensors with an expected life in air of 48 months will have an expected life 1/5 of that in 100% oxygen i.e. 10 months

Failure of a sensor can be due to various factors.

The usable lead can be used up.
The electrolyte can dry up.
The sensor can be physical damaged
The sensor can leak.
As the lead is used up and/or the electrolyte dries out the internal resistance of the sensor increases reducing the output.

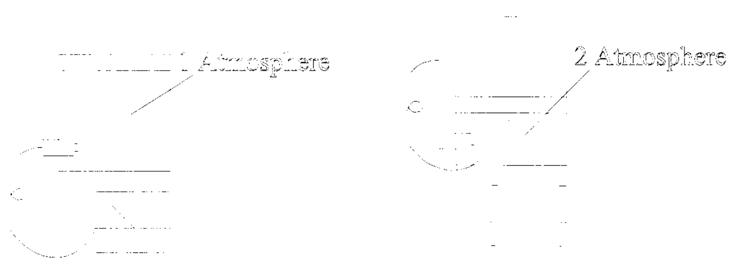
This can be checked by calibration in 100% O2 and checking that the sensor returns to at least 22% on re-exposure to air.

Sensor outputs

Pressure

Virtually all oxygen analysers measure the partial pressure
It is therefore important to calibrate the monitor at regular intervals (see manual).
Readings will be affected by altitude and Hyparbaric Chambers
Readings will be effected in close circuits under pressure

Applying Daltons law as the pressure increases the partial pressure increases. As the pressure decreases the partial pressure decreases.



Pressures in excess of 1Bar can be generated when the sensor is placed in a stream of gas e.g. the output of a CPAP flow generator .High flow rates can force gas onto the sensor faster than it can escape causing a back pressure on the membrane. This pressure is recognized as an increase in partial pressure.

The sensor can be mounted in virtually any position without changing its sensitivity .

The sensor measuring position should always include an escape route for the gas to the atmosphere. Particularly at high flow rates any resistance to flow will generate a back pressure upon the membrane.

The sensor operates best in a flow rate of 1- 5 litres per min with 10L/m as a maximum. Lower than 1L/min slows down the gas exchange on the sensor face and therefore slows down the response.

High flow rates have difficulty in clearing the gas unless open to atmosphere and can cause a back pressure.

Humidity and water

Humidity does not directly affect the accuracy of the sensor however :-

Excessive moisture or condensation on the sensor surface will block diffusion of oxygen to the sensor and render it inoperative. The sensor should always be facing down so that any droplets will have a chance to fall off the sensor membrane. In ventilator circuits the sensor is heavy and will lie at the lowest part of the circuit. Usually where rain out condensate collects

I high humidities the effect of water vapour in the gas can be calculated as follows.

Assuming STP Temperature = 25C pressure = 760mm and the gas is fully saturated 100% relative humidity

The Water vapour pressure from the standard tables is 23.756 mmHg

Vapour pressure tables exist which provide reference of water vapour pressure against temperature

%H2O =23.756 x100/ 760 = 3.13%

This is how much water vapour exists in the gas
In Air the original mixture dry contained 20.9% Oxygen the actual reading would be

20.9- (20.9 x 3,.13)/100 = 20.25 %

Error =0.65%

In order to obtain absolute accuracy the atmospheric pressure and temperature should be known. The relative Humidity should be 100%.

Using Oxygen Analysers

It is recommended that all Oxygen analysers employing galvanic oxygen sensors only be used a secondary measuring devices to verify the concentration of oxygen in gas mixtures

Battery Installation or replacement

Alkaline batteries are usually chosen because of their life and discharge characteristics. There can often be a point the internal stabilisation of the monitor electronics is critical upon the battery condition.

fig 12 Battery discharge curves

Sensor Installation

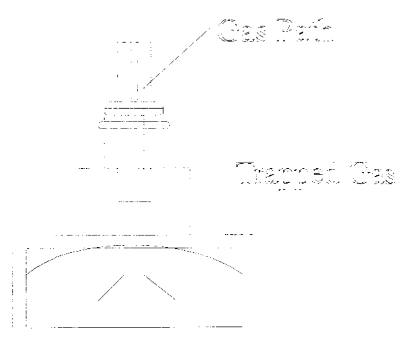
The gas barrier bags should not be punctured or have staples attached to them.
Visually inspect the sensor for damage or electrolyte leakage.

Allow the sensor a few minutes to stabilise after installation. Sensors are stored in special airtight containers or special gas barrier bags to slow down the electrochemical reaction during storage. During this period the sensor consumes the Oxygen in the container or bag leaving the sensor in Nitrogen. Some sensors sometimes go into a "sleep" mode whilst being stored and occasionally may require 15 - 20 minutes exposed to air before they stabilise and can be used accurately.
During installation and use do not touch or puncture the membrane. Oils from the skin can block the diffusion path.
Sensors which become exhausted or leak whilst in sensor holders will cause damage to the sensor holder unless they are removed immediately and the sensor holder washed with water.

Never store sensors for long periods before use.
Never Subject sensors to High Temperatures i.e. (Car rear shelf)
Never Freeze sensors (left in cars overnight)
Never Subject sensors to physical shocks.
Never Subject sensors to vacuum
Never Submerge sensors in liquids
Never Attempt to open a sensor.

Flow thru Divertor
The flow thru divertor is designed to be used only in conjunction with the tee piece and only in flowing gases. Flowing gas is diverted onto the sensor face and decreases the time it takes the sensor to respond.

Failure to remove the divertor in static gas can cause the response time to be lengthened substantially and gas can become trapped in the area between the flow divertor bottom and the membrane.
It is essential that moving gas be present when the divertor is being used. Do not use in Oxygen hoods , Oxygen tents or incubators etc.



Calibration

Calibration in Air 20.9%
Switch on the analyser Remove the Flow Thru Divertor if fitted Blow gently across the face of the sensor face. Wait for the sensor to show a dip in reading to about 17%, due to CO_2 in breath, recover, and then slowly stabilise.

Which ever method is chosen never hold the sensor in the palm of the hand as heat from the body can effect the reading.

Sensors deteriorate very slowly and near the end of their useful life may show a slow downward or upward drift in reading soon after calibration.

Sensors should be checked periodically with 100% Oxygen.

Oxygen Calibration

The method easiest to use anywhere is to place the sensor without the Flow Thru divertor in a plastic bag with small pin holes. Ensure the neck of the bag is held closed. Slowly introduce 100% Oxygen via a small tube and Flush several times. When stable set calibration to 100%. Remove the sensor from the bag and without moving the calibration control allow the analyser to measure the Oxygen in the air . The reading should return to between 20% and 22%. If the sensor is outside these limits, repeat the calibration in 100% Oxygen and try again with air. Ensure all the Oxygen has been flushed out of the sensor during the air calibration. In a confined space ambient Oxygen levels may build up beyond 21%. Check in fresh air. Allow adequate ventilation in measuring area.

The most accurate method of measuring 100% oxygen is to use the Flow Thru Divertor, Tee Piece and a two meter lengths of tubing

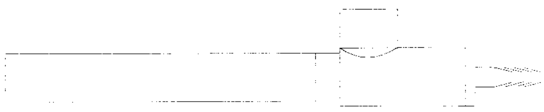


Fig 14 O2 Calibration with Tee piece

Flush with 100% Oxygen at a flowrate not exceeding 5 Litre/minute (a gentle stream of gas giving an audible hiss). When the reading is steady set 100% with the calibration control. Flush with Air. The reading should fall and reach a level between 20% and 22%
When analysing Oxygen mixtures above 50% always calibrate in 100% before the measurement

Do' s and Don'ts

DO

* Read all of the directions before using for the first time
* Calibrate before use
* Keep the unit, sensor, and connections dry
* Calibrate after replacing the batteries
* Calibrate after replacing the sensor
* Calibrate in air before every reading
* Make sure the sensor is properly attached
* Visually inspect the sensor for leakage or water on the sensing surface before use
* the plastic Flow Thru divertor when using the Tee Piece
* Remove the Flow Thru divertor when measuring in a bag
* Clean the case using only with a damp cloth and mild detergent
* Remove the batteries prior to extended storage

DON'T

* Use the analyser if you suspect any malfunction
* Overheat or freeze the sensor
* Open or try to repair a leaking or broken sensor
* Immerse the sensor or instrument in any liquid
* Pass hot or cold gas mixtures over the sensor
* Expose the unit to radio, short wave, microwave, X-Ray, high frequency, or electromagnetic Radiation
* Use cleaning agents or liquids in the cable receptacles or around the battery compartment
* Place the analysing unit in a water vapour saturated environment
* Expose the analyser or sensor to excessive sunlight
* Expose the analyser or sensor to temperatures greater than 40 C (106 F) or less than 0 C (-32 F)
* Use if low battery indicator shows

Storage of sensors.

If it is left inside the sealed gas barrier bag its life expectancy should only deteriorate by 1/20 of its in air life per year. A shelf life of 1-3 years can be expected if sensors are stored correctly.

Warranty

The bags should be examined before opening for signs of leakage or damage. The manufacturer gives a one year limited warranty on the sensors from the date despatched. This is limited to faulty workmanship or materials but not exhaustion.

Testing Sensors

All sensors can be checked with a simple Digital multimeter and a range of cables.
T1 , T-2 , T-5 & T5A. The sensors require an equivalent to the temperature compensation circuit. i.e. approximately 200 ohms across the sensor. The current output can be measured.

R22,R23, R24 all have voltage outputs
Air 10.5 Mv +/-_ 3.0 Mv
100% Oxygen 50Mv +/- 15 Mv

The **R-15** should have a load of 600 Ohms and voltage can be measured
The **R-23** has two outputs therefore half the R-15 output will be measured.

Types of Sensor .

T1 and T2 Galvanic sensors are usually used in sensor holders and originally had analogue readouts.
T2 is only to be used where Nitrous Oxide will be present.

T5 and T5A were the first long life super cells from Telydyne and are only used in the TED 140 and TED160 monitors .They require electronics to drive the display The T5A is the Nitrous Oxide version.. However unlike the T2 the T5A has the same life as the T5 and can be interchanged.

The latest O.E.M monitors are staring to use R-17 sensors.

Draegar sensors.

Draegar sensors are dual cathode sensors and used in The Ohmeda Oxygen monitor , Draegar Oxygen monitor and HP Oxygen monitor module can be replaced safely by the R-15.
The latest anaesthetic ventilators , and Intensive care ventilators from Draegar have been specifically designed to use both cathodes. These sensors can only be replaced with the R23. Draegar incubators also use dual oxygen sensors and should be replaced with the R23.

It is important to be aware that the Draegar incubator appears to monitor the deterioration of the sensors and expects the sensors to track faithfully throughout their lives.
In line with Draegar they should be used in pairs . Never add only one sensor or the tracking system may prematurely reject it.

The **R22**, has been used for many years with Siemens ventilators.
The Servo 300 was specifically designed to take the smaller Catalyst Research sensor.
Teledyne have now an equivalent in the **R24**. This sensor is 25% smaller and therefore has a shorter life expectancy.

The **R-13** is a direct replacement for the Ventronics sensor.

Problems with Sensors
Problems with sensors fall into three categories.
Electrical output failure,
No output the sensor is usually exhausted . These sensors are usually out of warranty or just inside warranty.. A proportion of sensors will leak. Sometimes the leakage is microscopic and cannot be easily observed.
Low output:: As with No output
A very small percentage of sensors fail within warranty due to exhaustion . Those that do usually fail early in there life cycle.

Erratic output: the erratic output can be caused by the sensor nearing the end of its life .
It can also be caused by mistreatment and physical abuse.

with T-1 & T-2 C1R & C2R the connections in the sensor holder can become dry joints .
A broken temperature compensation will generate a high output.
Mechanical failure,
Gross leakage is easily recognised
Anode disintegration can cause the sensor to rattle
Low levels of electrolyte can change the reading if the sensor is inverted.
Intermittent output due to sensor connector particularly T-7

User problems
Sensors are often returned with no fault found.
Usually the user has not tested the correctly.
Out of the bag new.
T-1 & T-2 type sensors have no thermal compensation acting as an electrical load. When the shorting clip is removed the sensor goes open circuit. It can take up to 8 hours to stabilise. Sensors reading high should either have the shorting clip replaced or be left in a working sensor holder plugged into the instrument for several hours.

R-15 & R23 have a similar effect where they appear to go to sleep. This is due to all the Oxygen in the sealed bag being use up leaving the sensor in a Nitrogen atmosphere. Many sensor are returned reading low but on arrival no fault is found. In most ventilator circuits the sensor is heavier than the tubing and lies at the lowest point. Water collects in the sensor and gives a low reading or very slow response. By the time it reaches us the water has dried out.

Breakage of **T-7 threads**.
This will only happen if the sensor is dropped and hits the floor on the corner of the shoulder.

Sterilisation and Disinfecting Sensors.

Teledyne's recommended solutions for disinfecting sensors are either a: Sonacide (potentiated acid glutaraldehyde

b: Cidex (activated dialdehyde)

To disinfect the sensor dip it for one minute in either of the above solutions. Then using a soft absorbent tissue, blot dry the sensing membrane. Place the sensor membrane side up on a paper towel for 10-15 minules to allow any solution trapped between the contact plate to drain.

For complete Sterilisation to destroy various tuberde vacilli and resistant spores immerse the sensor for 60 minutes in sonacide and maintain a temperature of 60C.

A brown ring may be observed after the hour under the white hydrophobic sensing membrane This will have no effect on performance or sensor life.

Cidex can also be used although a period of ten hours is required.

Due to advances in materials and changing contamination always check with the sterilisation solution manufacturer before use.

Never autoclave an Oxygen sensor.

With sensor such as the R17 &n R-22 with built in temperature compensation the output connectors should be kept dry and not immersed.

Chemicals allowed to ingress inside the connector can permanently damage the sensor.

If the sterilisation solutions do enter the connector it should be assumed that the sensor will be damaged.

However if the connector is washed out with copious amounts of fresh water and allowed to dry the sensor may recover.

After sterilisation the sensor should be checked for Calibration in Air & 1000/0

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