About the measurement of Oxygen

This document provides some basic knowledge of instruments that measure oxygen at ambient temperatures, both dissolved oxygen in liquids, gaseous oxygen, pure oxygen and oxygen in gas. It also includes information of measurements that often are made alongside oxygen measurements. OxyGuard International A/S is the first company founded specifically to design, manufacture and market dissolved oxygen meters, monitors, controllers and alarm units, and information of specific instruments can be found in the appropriate brochures.

Some basics

Oxygen, O2, is the most important building block of nearly all life here on Earth. The energy we, together with other life forms, use to live and grow comes basically from the chemical combination of oxygen with carbon and hydrogen. This forms carbon dioxide and water, that plants, with the help of energy from sunlight, convert back into food for us and all other manner of beings. Only some recently discovered deep-sea creatures do not use this mechanism.

Air consists of 20.9% oxygen. Despite the vast amounts of fossil fuel that are now being burnt this figure remains, as yet, quite constant. Air-breathing beings have no trouble obtaining the oxygen they need – there is almost 1.5 gram of oxygen in every 5 litres of air, and air mixes and moves around easily. For aquatic life the situation is different – you need 100 litres of cold water to get 1 gram of oxygen. Even more water is needed as the water gets warmer, boiling water contains no dissolved gas. In oceans and lakes it can take some time before "used" water is "refreshed", and areas or rather volumes, of oxygen depleted water can move around for long periods of time harming plants, mollusks and other slow-moving aquatic beings. Environmental monitoring of dissolved oxygen and other parameters shows where we should be careful not to place further stress on nature. Modern man uses aquatic life forms – he raises fish for food, uses bacteria to break down waste water. Both are processes where oxygen is measured and controlled to ensure progress as desired.

In other situations oxygen is unwanted. In the water/stream circuit of a power plant is causes corrosion. In beverages it can change the taste. In a flammable gas it can cause an explosion. In food packages it can speed deterioration. These are instances where very low levels of oxygen need to be measured.

Another important use of oxygen measuring equipment is in the environment. The human population explosion entails a degree of pollution that seriously endangers natural life forms. The measurement of oxygen levels gives a good indication of at least the basic level of pollution.

Some definitions

Oxygen Probe:	A device that senses the amount of oxygen present.
Oxygen Meter:	A device that incorporates an oxygen probe and a display to show the amount of oxygen.

Oxygen Monitor:	An oxygen meter that incorporates some sort of surveillance or alarm device.
Oxygen Controller:	An oxygen meter with an outpur that is used to keep the oxygen content at or above a pre-set level.
Oxygen Alarm Unit:	An oxygen meter with one or more outputs that indicate when the oxygen level is too low or too high.
% Saturation: (%sat)	For dissolved oxygen, the ratio between the actual oxygen content and that of water that is saturated with air. Note that 100% saturated warm water contains much less oxygen than 100% saturated cold water.
% Volume:	The volumetric percentage of oxygen present in a gas. Air = 20.9%, pure oxygen = 100%.
Mg/1:	Dissolved oxygen content in milligram oxygen per litre. 100% sat water at 20 degrees Celsius contains 9.1 mg/1.
Ppm:	Dissolved oxygen content in parts per million by weight. Essentially the same as mg/1, since 1 litre of water (depending on temperature) weights 1000 grams.
Ppb:	Parts per billion dissolved oxygen (microgram per litre). The DO of steam turbine water and some beverages is usually in the 5-50 ppb range.

Oxygen Probes

Once upon a time oxygen content could only be measured by chemical means. Today the easiest and most accurate way of measuring oxygen is to use an oxygen meter, and most oxygen meters, especially dissolved oxygen meters, have membrane cover polarographics sensors that generate an electrical current when they measure oxygen.

Until the Oxyguard probe was introduced Clark cells were the predominant type of oxygen probe, but today the Oxyguard probe (and copies of it) is the most widespread since it has some inherent advantages over Clark cells. It is worthwhile to note that if you come across a spherical or cylindrical oxygen probe made of black plastic about 6cm in diameter, it is most likely either an Oxyguard probe or a copy. The Oxyguard probe is of the Mackereth cell type. The main advantages of this type of cell are:

- You do not have to apply a potential to it to make it work, it generates its own electricity;
- The Oxyguard type of sensor is lways ready for use and it does not need to “warm up”
- This type of sensor reacts quickly to changes in oxygen level;
- The Oxyguard type cell does not decay or loose sensitivity with age, it maintains its efficiency so you **do not have to perform maintenance on a regular basis**.

You do, of course, need to keep the membrane of any membrane covered oxygen sensor reasonably clean since deposits (bacteria, fat, etc) on the membrane will act as a barrier to the oxygen the cell is trying to measure.

The use of oxygen meters, oxygen monitors and oxygen controllers – both for dissolved oxygen and gaseous oxygen – has increased dramatically during the last 15 years ie. Since the introduction of the Oxyguard oxygen probe and oxygen monitoring equipment. Oxyguard International A/S was founded specially to meet the growing need for dissolved oxygen and gaseous oxygen meters, monitors and controllers, and since then the need for more precise knowledge of and control of oxygen content has gone hand in hand with the emergence of new types of oxygen meters, oxygen monitors and oxygen controllers.

The following pages show where oxygen probes, oxygen meters, oxygen control and alarm equipment are most often used.

Fish Farming – Aquaculture
This industry was where the new type of dissolved oxygen equipment made its breakthrough. Fish farmers needed multi-channel DO meters ie multiple point of measurement DO meters that they could afford. They also needed DO monitoring and DO control. DO monitoring should encompass alarm units with both high DO alarm and low DO alarm.

Equipment introduced by Oxyguard in 1987 provided all this and was soon in use all over the world. We are of course talking about intensive fish farming. If you only have a few fish in a large pond full of clean water you won't need a lot of equipment. Commercial fish farmers, however, must take the most of the resources available to them, and there is a general tendency to progress from flow-through farms where all the water flows through the farm only once to partial and fully recirculating farms, where the water is cleaned and topped up as needed.

Inlet water DO measurement and control
Here a feed-forward controller with two DO measurements can be used. An upstream DO meter determines whether oxygen injection is necessary or not and a downstream DO meter gives feedback so that oxygen injection can be controlled precisely. An oxygen level alarm on the downstream DO meter can give warning of malfunction or extreme conditions needing manual intervention.

Re-circulating water treatment
This is a science in itself. The water is cleaned and filtered through mechanical and biological filters. Ozone can be added to "burn off" pollutans, either by direct ozone injection or by UV ozone activation. This process can be controlled using a redox or OPR measurement. A new type of redox or ORP probe with built-in redox electrode cleaner eliminates passivation of the redox electrode and makes this forms of ozone injection control reliable. The pH of the water is measured and controlled using a pH meter and

pH controller. The dissolved oxygen content is measured and pure oxygen is injected. This oxygen injection can also be used to strip off carbon dioxide. Often only a small proportion of the water is oxygenated at high pressure. The resulting super-saturated water is mixed with the main flow to give healthy DO levels in the growth tanks. Pipe-mount DO probes, flange mount DO probes or flow cell DO probes can be used in such high pressure oxygenation systems.

Hatchery and growth tanks
Water level as well as dissolved oxygen should be measured in each tank – the water supply to one tank could be cut off. Oxygen level alarms are set on the DO measurements. Aeration or oxygen injection to each tank is not often practiced in smaller indoor tanks – oxygen is added to the inlet or re-circulated water. Aeration or oxygen injection is, however, seen in larger tanks, requiring a separate DO meter with DO controller system for each tank. This is easily done with modern multi-channel DO metering and control equipment.

Sea Cages
These present a special problem, since it is difficult to control the DO content of the sea. DO measurement is, however, very important because feed uptake and DO levels are interconnected. Intensive feeding after fish have experience low DO levels can not only be a waste of food, but can actually harm the fish. The measurement of dissolved oxygen levels enables feed to be dosed optimally and, if relayed to the shore can warn that the cage should be moved if extremely low DO levels should occur.

Transport tanks
DO measurements should also be performed during transport to the processing plant – a lively, healthy fish gives a better finished product that a half-dead one. Another situation requiring DO measurement is the transport of juvenile fish (eg smolt) to tanks or cages for on-growing.

Oxygen generator control
Pure oxygen meters (oxygen purity meters) oxygen controllers and oxygen alarm units are also used in aquaculture. The purchase of liquid oxygen in bulk is often the most economic solution, but there are many cases where oxygen generators are installed locally. Two of the many advantages of using pure oxygen are that 1) it is possible to super-saturate the water with oxygen and 2) you save pump energy since pumping air means pumping 79% nitrogen and "only" 20.9% oxygen.

Waste water treatment
This is another area where dissolved oxygen measurement is used to increasing degree – it is no longer enough just to filter the water and dump the detritus in the sea. The larger part of the waste is mainly organic, and this must be broken down in sludge tanks and the effluent water controlled and treated as necessary.

Sludge tank DO measurement and control
Here single-channel dissolved oxygen meters, 2-wire dissolved oxygen probes and dissolved oxygen controllers are met. The dissolved oxygen level is kept at approximately 2mg/1.

Effluent monitoring and oxygen level control
Effluent is monitored using 2-wire dissolved oxygen probes or, single-channel dissolved oxygen meters. Single channel dissolved oxygen controllers can be used to control aeration or oxygenation. Clean effluent should have a 100% air-saturated DO content. If the effluent still has a BOD, ie. If it contains organic pollutants that consume oxygen when they break down, pure oxygen can be injected to give an extra oxygen content, ie. a super-saturated DO level.

Here too pure oxygen can be used to save energy instead of pumping air, so pure oxygen meters (oxygen purity meters) oxygen controllers and oxygen alarm units are used for oxygen generator control.

The DO monitoring and control practiced in waste water treatment plans is supplemented with pH measurement and control. Flow measurement, suspended solids measurement, sludge blanket detection, conductivity measurement, nitrate measurement and phosphate measurement are also all used to enable the efficient and effective cleaning of the waste water.

Safety monitoring
Both oxygen detection in flammable gas and oxygen monitoring in ambient air are examples of this. Blanket gas is often used where flammable substances occur. Blanket gas is gas that cannot burn or sustain fire, ie it does not contain oxygen. Volumetric oxygen measurement is carried out both on the blanket gas and the surrounding air, the latter for worker safety. Special versions of the Oxyguard probe are approved for use in potentially dangerous atmospheres, ie in EX classified areas.

Food and Beverages
Many foodstuffs are packed in a Modified Atmosphere Packaging or MAP package where a low or controlled oxygen level is necessary. MAP oxygen meters that extract gas from a package as well as on-line oxygen meters are used. DO levels in some drinks, such as beer, should be kept in the PPB range. Recently the practice of adding oxygen under pressure to bottled water to make oxygenated water has become more common. Both these dissolved oxygen measurements need DO probes that can be cleaned at elevated temperatures without being removed from the pipeline (CIP –Clean In Place – use).

Environmental monitoring
Dissolved oxygen data loggers can be left to record DO fluctuations in lakes, rivers etc. Deep sea oxygen probes are used in oceans and deep lakes or fjords. Profiling probes with fast response are used to map the dissolved oxygen content of lakes and fishing waters. Profiling probes are not only raised and lowered in the water, but also towed through the water at different depths to give a total picture of the state of the area concerned.

Hand held oxygen meters

These are found in numerous shapes and sizes. A hand held or pocket size dissolved oxygem meter should meet certain criteria. It should be a waterproof DO meter, show DO in both % sat and mg/1 (ppm), have automatic temperature compensation and should always be ready to measure. It should be as near as possible to a maintenance-free DO meter. More advanced types should have automatic calibration and pressure compensation as well as salinity compensation and data logging or data recording functions. The meters of the Oxyguard "Handy" range are examples of such meters.

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