# Oxygen Monitors Optimize Quality and Flavor PART 1: Amperometric and Optical Sensors

## Introduction

### Oxygen: can't bottle with it; can't ferment without it.

Few things are as troublesome to a brewer as oxygen. Even a small amount introduced at the wrong time causes oxidation. But, oxygen is also a critical element during the fermentation process. From wasted brewing materials and operator resources to souring a consumer's experience with off flavors, there are plenty of reasons to pay close attention to oxygen throughout the brewing process. The good news is that with the proper tools to monitor and measure oxygen throughout the brewing process, a brewery can perfect flavors and keep batches on store shelves longer.

Benefitting from over 40 years of experience in oxygen measurement for the brewing industry, Hach (working with the Orbisphere brand) is well placed to evaluate both amperometric and optical technologies. This two-part application note series examines oxygen monitoring tools and methods, helping breweries ensure their product quality long after batches leave the brewery.[1,2]

### PART 1 of this series covers critical topics when choosing an oxygen sensor, including:

- The effects of oxidation on the brewing process
- Amperometric and optical oxygen sensors
- Process conditions affecting oxygen measurement.

### PART 2 of this series covers topics critical to day-to-day operations, including:

- True zero for oxygen sensors
- Drift and sensor stability
- Sensor calibration
- Sensor maintenance.

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## Oxidation Sources

The effect of oxygen on the different stages of beer production, in addition to the importance of maintaining appropriate oxygen levels, has been reviewed in detail in other papers.[3,4] Once the fermentation step is complete, it is critical to avoid any further oxidation of the beer to maintain the quality, taste, and shelf life of the final product.

Expert tasting panels can easily recognize oxidized beers. Noticeable changes take place shortly after packaging if dissolved oxygen levels are too high. These changes are accompanied by color and flavor instabilities. The most detectable off-flavor that arises from oxidation is a "cardboard" or "wet paper" taste produced by elevated oxygen levels. Conversely, careful beer handling in the brewery can result in packaged dissolved oxygen values of less than 20 µg/l. At this level shelf life is greatly extended, so accurate oxygen monitoring is necessary if oxygen levels are to be controlled during the beer production process.

A major source of air contamination in bright beer occurs when it is transferred between vessels. After every tank transfer or operation such as filtration, the beer should be checked to ensure oxygen levels have not changed.

Other sources of air contamination and oxygen ingress include inadequately purged vessels, leaking pump glands or valves, and filter aid dosing pumps. By measuring throughout the process, it is possible to identify the source of any oxygen contamination, giving brewers the opportunity to minimize it.

## Available Methods to Monitor Oxygen

Traditionally, the dissolved oxygen (DO) sensors employed by the brewing and other industries were membrane-covered amperometric sensors. Oxygen diffuses through the membrane, and the electrical current generated by the electrochemical reaction is in direct proportion to the partial pressure of the oxygen in the sample. The proportionality constant can be determined by a suitable calibration procedure using air as a source of known oxygen partial pressure.

Optical oxygen sensors have gained popularity over the last decade and are now the most used in the beverage industry. Since optical oxygen sensors became available to the beverage industry, optical sensing of oxygen has been based on the measurement of the fluorescence of a dye/indicator illuminated with light; this dye fluorescence being quenched by the presence of oxygen (the more oxygen the faster the fluorescence disappears). Oxygen concentration can then be calculated by measuring the decay time of the fluorescence intensity. The higher the oxygen concentration, the shorter the decay time is. By modulating the excitation, the decay time is transformed into a phase-shift of the modulated fluorescence signal, which is independent of fluorescent intensity and thus of potential aging.

For both methods, Henry's law (William Henry [Chemist], 1803) provides the link between partial pressure and dissolved concentration in the sample. Figure 1 shows the fundamental differences of the raw signal behavior against the content of oxygen for both the amperometric and optical methods.

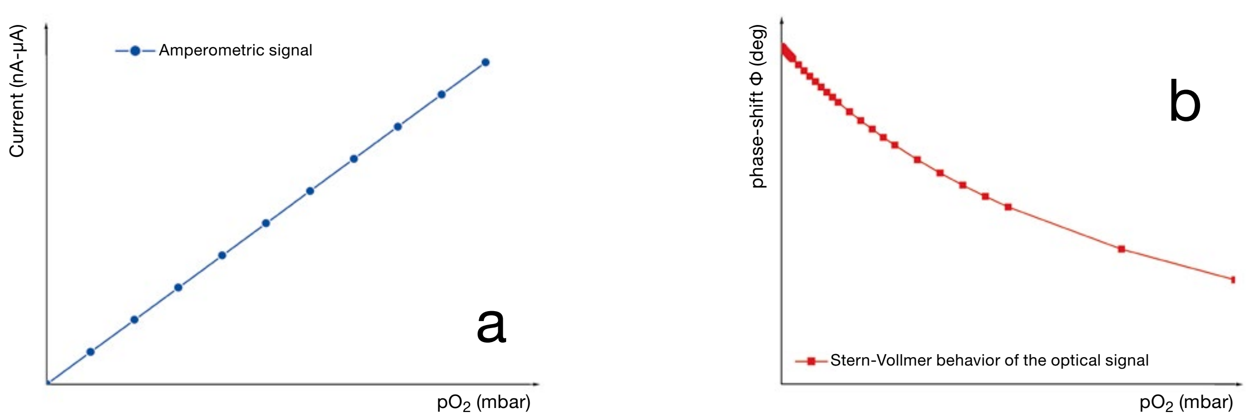


*Figure 1: Differences of raw signal behavior against the content of oxygen with both sensors*

## Effect of process conditions on the measurement

Amperometric technology consumes the oxygen that is measured and therefore requires a minimum flow to work accurately. This is not normally an issue in a beer process where the flow is sufficiently high. When the production line is stopped however, the absence of flow and hence oxygen consumption typically leads to low oxygen readings. Standard amperometric sensors are adapted for pressure conditions found in-line, but changes in flow or pressure can cause the membrane to vibrate and generate noise in the measured signal. Pressure shocks caused by valves opening or closing can generate spikes on the oxygen signal whose duration strongly depends on the sensor design.

The effects of lack of flow, flow variation, and sudden pressure changes are illustrated in Figure 2. In Figure 2a, the spikes caused by the opening of a filling valve are observable, whereas Figure 2b illustrates how the amperometric reading decreases over time in the absence of flow.

Although optical sensors do not intrinsically require any flow to measure accurately, a minimum flow is required to refresh the oxygen content in the spot and provide representative sample measurements. Static pressure and pressure changes have no effect on the measurement unlike amperometric sensors.

Figure 2a shows the absence of any pressure effect on the measurement as a valve is opened or the line stopped. Figure 2 also demonstrates the accuracy of the oxygen reading against the Orbisphere amperometric sensor. On a lager beer sample with an approximate content of 2 ppb oxygen both sensors measure within 1 ppb (Figure 2a). On beer/syrup mix with an oxygen content of 135 ppb both measure within 3 ppb (Figure 2b). With such low deviations from the Orbisphere A1100 reference, the Orbisphere M1100 offers the advantages of an optical sensor.

Figure 2b shows the continuous accurate reading in the absence of flow. When amperometric sensors are exposed to high oxygen content and high temperature, such as during Cleaning In Place (CIP), this can shorten maintenance intervals. However, such effects can be minimized by switching the sensor to stand-by position when the temperature is high.

Although optical sensors are also CIP compatible, exposure to high oxygen levels and high temperatures is the principal cause of drift which results in more frequent calibration. As for the amperometric sensor, an appropriate system configuration can protect the sensor by switching it off during high temperature conditions.

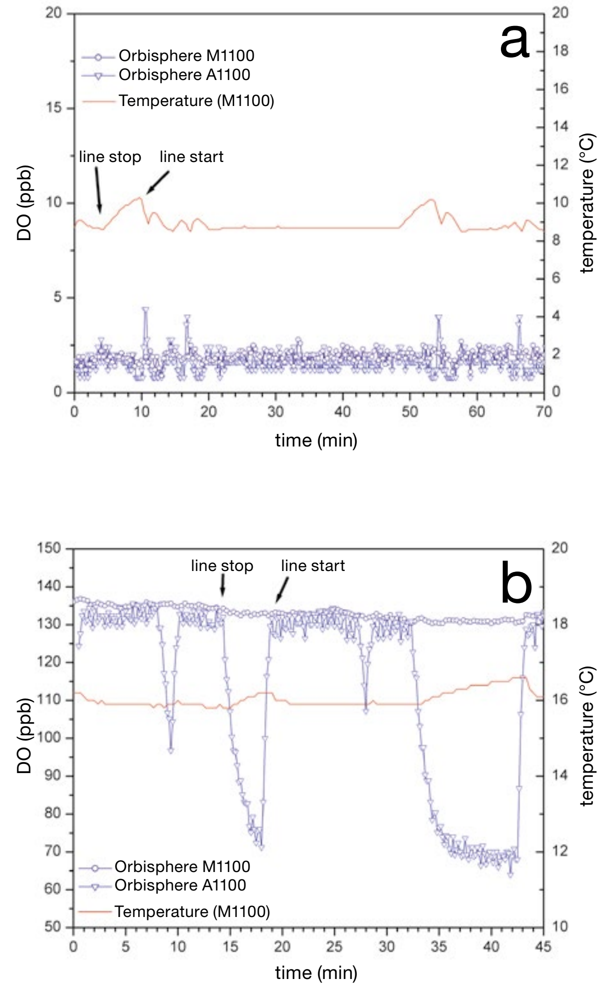


*Figure 2: Effects of lack of flow, flow variation, and sudden pressure changes*

## Conclusion

The Orbisphere M1100 offers precision and accuracy, allowing brewers to confidently maintain low oxygen levels, thereby controlling beer oxidation and improving flavor stability. Robust optical technology without membranes or electrolyte makes the M1100 sensor highly resistant to rapid process and flow changes, reducing and simplifying maintenance. This adds up to increased production uptime and a lower total cost of ownership.

The Orbisphere A1100 amperometric sensor gives the best detection limit (± 0.1 ppb), and the easiest calibration method (single point in air) and is an ideal solution for water applications requiring high accuracy. However, the M1100 optical sensor is the best solution to fulfill brewers' needs, offering a fast response time and reliability with limited maintenance and calibration requirements, thus providing the most cost effective solution to accurately monitor oxygen in beer.

*Orbisphere M1100 Optical Dissolved Oxygen Sensor*

*Orbisphere A1100 Amperometric Dissolved Oxygen Sensor*

## References

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2. Dunand F.A., Ledermann N., Hediger S., Haller M., Weber C., PowerPlant Chemistry 2007, 9(9), 518
3. Klein C., Dunand F.A.; Brewing and Beverage Industry International, 2008, N° 1, 22.
4. O'Rourke T.; The Brewer International, 2002, March, 45.

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