Measurement of dissolved oxygen in wort

- Oxygen monitoring permits the injection of oxygen instead of air
- Continuous measurement allows automatic feedback control
- In-line sensors avoid sample loop blocking and product contamination
- Beer loss in spent yeast is minimized, for substantial cost savings

Application description

Wort is the liquid produced by extracting sugars from germinated barley (malt) with boiling water. The wort is cooled, and after aeration and addition of yeast, it is allowed to ferment to produce beer. Although it is generally desirable to keep oxygen (O_2) out of the brewing process, at the fermentation stage it is necessary to actively increase the dissolved oxygen content.

Yeast requires O_2 to synthesize the unsaturated fatty acids and sterols necessary for life and growth. The amount of air or oxygen required depends on the gravity of the wort, the yeast strain used and the brewery design.

The dissolved oxygen content may be adjusted from time to time depending on the yeast performance and beer quality. The normal dissolved oxygen range is 7-14 parts per million (ppm). For high gravity brewing operations 15-20 ppm of oxygen is required for fermentation, it is now common practice to make and ferment worts with a relatively high initial extract content (gravity e.g. 16 °Plato) mainly for financial benefit.

Hot wort is cooled with a plate heat exchanger (called a wort cooler) and is virtually air free (having been boiled). Yeast will be added to the wort, and for the yeast to grow it is necessary for the wort to contain high levels of O_2. Wort can be aerated by injecting air but now that in-line analyzers are available, there are a number of reasons why injection of pure O_2 is preferred, including:

1. Injection of air combined with modern tall conical fermentation vessels causes huge foams to occur at the top of the vessel.
2. Air needs to be sterilized before it is injected.
3. Injection of O_2 allows very high dissolved O_2 values if desired.
4. The required amount of O_2 is small, so the cost is negligible.

Oxygenation is also preferred for higher pitching temperatures or higher wort gravities whereas aeration is used for yeast strains requiring 8-9 ppm of O_2 for normal wort gravities. At higher altitudes it is necessary to use pure O_2 in order to achieve dissolved O_2 levels higher than 7 ppm whereas at the coastal regions dissolved O_2 levels up to 10 ppm can be achieved using air.

Tightly controlling the O_2 injection levels ensures that fermentation times are always the same, leading to a consistent beer flavor. If too little O_2 (or air) is injected, yeast growth is impaired. This slows the fermentation process and the resulting increased fermentation time can potentially create unwanted off flavors, higher ester concentration. Too much O_2 (or air) leads to excessive yeast growth, which results in beer losses as the yeast is discarded at the end of fermentation. This may also lead to increased flocculence and fobbing, and deterioration in flavor.

Oxygen is introduced into the wort by injection into the filling line; the oxygen system itself should give finely dispersed bubbles into the line. Modern devices have been developed to ensure total gas dissolution. They are based on propriety designs with extremely high internal pressures and turbulence. Oxygen is best used in these devices to avoid excess gas volumes. Some modern devices guarantee total dissolution within 2-4 meters of injection. It is accepted that control must be exercised over the oxygen injection to ensure uniformity of product, setting a constant volume flow rate of the gas does this. The optimum operation of the injection system is dependant on other factors, such as wort line pressure and the wort flow, rate. A mass flow meter is used to control the oxygen injection system. Traditional Brewers rely on the mass flow calculation as they believe it produces a reliable consistent result, whereas the oxygen reading may deviate from the mass dissolution.

Important notes

- Oxygen needs to be measured and controlled using an oxygen feedback control measurement system to give effective oxygenation.
- Mass flow meters use a calculated value based on line pressure and flow rate, any leaks in the system will not be identified using the calculated mass flow reading.

Installation recommendations

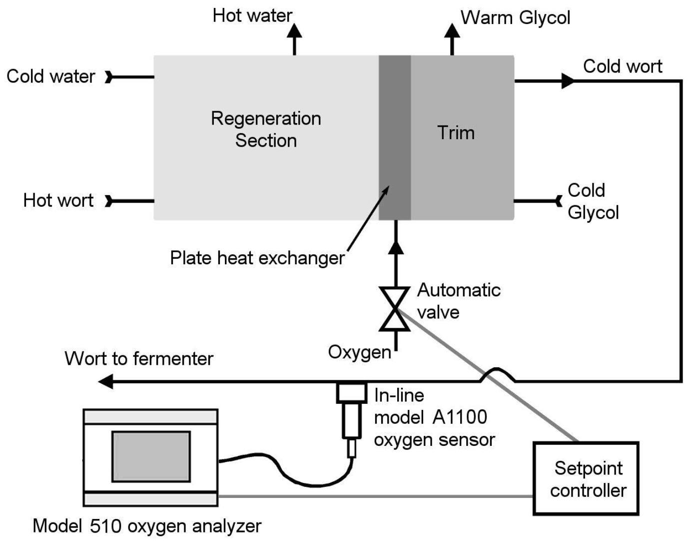
The O_2 sensor must be installed directly in-line (see installation schematic below). Wort contains particles of barley husk and these could block off-line sample tubes. At this early stage, it is vital that no microorganisms get into the wort. It is therefore important that in-line systems able to withstand full CIP are used. Systems with narrow bore sample tubes would be difficult to sterilize and should be avoided.

To allow accurate measurement of the injected gas, it is important that no bubbles are present when the wort reaches the O_2 sensor. This is accomplished by injecting the gas into the second (trim) section of the wort cooler, or by using modern gas injection systems that guarantee total dissolution as described above.

The gas injection rate is controlled with a feedback loop consisting of a set-point controller and an automatic valve connected to the O_2 analyzer signal. In this way, specific dissolved O_2 levels can be maintained automatically with great accuracy (better than ±0.2 ppm).

Regular CIP (Clean In Place) is harsh on the sensor and a thermal cut off at 25^{o}C is necessary along with regular sensor maintenance. Optimal sensor performance is obtained with the 29552A type of membrane, the use of a grill on top of the sensor is not recommended in order to prevent fouling of the sensor head.

Installation diagram



Frequently asked questions

Q. What should the maximum error be when comparing an In-line and portable oxygen analyzer in wort?

A. A 0.05ppm maximum difference.

Q. If the portable and in-line differ in oxygen concentration when measuring at the same point what could be the possible causes?

A. Incorrect sensor maintenance and calibration.

Q. If the portable oxygen measurement is taken downstream of the in-line oxygen measurement and the readings differ (portable higher) what could be the cause?

A. This would indicate the oxygen is not in solution at the in-line analyzer. Using the calculation above, calculate the % dissolution at the in-line and % dissolution at the portable point. Ensure the oxygenation system is obtaining a constant flow rate and there are no visible leaks. Assess the capability of the oxygenation system and ensure the in-line is installed in the best position possible.

Q. Can I measure accurately after yeast injection?

A. No, yeast is normally added during part of a run or on the first or second brew, measure when yeast is not added.

Q. How do you calculate dissolution of oxygen?

A. Dissolution is calculated as a percentage using the following formula:

$$\frac{\text{Wort dissolved } O_2 \text{ (ppm)} \times \text{Wort flow rate (hl/hr)}}{100 \times O_2 \text{ mass flow (kg/hr)}} = \text{\% Dissolution}$$

Note that mass flow can be calculated from l/hr to kg/hr as follows:

$$\frac{\text{l/hr}}{1000 \text{ l/m}^3} \times 1.429 \text{ kg/m}^3 = \text{kg/hr}$$

Recommended systems components

Model	Description
In-line Analyzer	
510/A00/P1C00000 or 510/A00/W1C00000	Orbisphere 510 oxygen (EC) instrument, panel mount, 90-240 VAC, 0/4-20mA analog output, RS485
	Orbisphere 510 oxygen (EC) instrument, wall mount, 90-240 VAC, 0/4-20mA analog output, RS485
A1100-S00	Electro-Chemical oxygen sensor, Stainless Steel, Maximum pressure 100 bar, with Smart capability
29552A-A	Recharge kit of 4 pre-filled cartridges with premounted 29552A membranes for A1xxx oxygen sensors. Includes o-rings, cotton filters and cleaning tools
29501.0	Stainless steel sensor socket with EPDM O-rings for welding to stainless steel pipe.
Portable Analyzer	
3650/111	Orbisphere 3650 oxygen (EC) instrument, portable, battery powered. Single channel, thermal cut-off, RS232 (serial) output
A1100-S00	Electro-Chemical oxygen sensor, Stainless Steel, Maximum pressure 100 bar, with Smart capability
32007W.030	Flow chamber in Delrin with 6 mm 8970 stainless steel Swagelok fittings for use with liquids with suspended particles. Supplied with EPDM O-rings.