Application Note

Dissolved Ozone Measurements with EC Sensors: Installation & Calibration According ASTM D7677-11

Introduction

In the last three decades Ozone has become a very important and efficient tool to achieve high quality pharmaceutical grade water. There are several reasons for this: Firstly, because of the quick, broad and powerful sanitization efficiency. Secondly, because it is easy to generate ozone directly in water without creating by-products. Thirdly, because it is easy to remove it with a 254nm UV light, a positive consequence of ozone's limited lifetime in water. And, last but not least, the use of ozone also helps to reduce costs when compared to other techniques of water sanitization.

This paper will address two main topics that are critical for the effective use of ozone within the water processes of the life science industry. First, two main installation variants of ozone monitoring in process water will be identified. Second, calibration methods will be discussed, including air calibration. These topics are now well described in the ASTM D7677 Standard Method [(1)] published in 2011.

Fig. 1 Hach EC Ozone Sensor

Ozone Sensors for Ozonated Water Loops

Sensors are available using either UV absorption or electrochemical (EC) technologies. We will focus here on this last technology that is also described in the ASTM D7677-11 standard.

Basically, an EC sensor for ozone receives a voltage between two electrodes immersed in an electrolyte. A current is generated, that is proportional to the ozone concentration that diffuses through the membrane separating the sensor electrolyte and the measured sample.

EC technology has progressed over the years and has now reached a high level of maturity, providing benefits including: selectivity, average lifetime of more than 10 years, measuring optimization with different membrane types, low cost of ownership (replacement of electrolyte and membranes) and finally on site air calibration reproducibility. The mechanical design integrating three electrodes provides a very low and stable residual removing the need for a zero calibration.

There are three main locations for the ozone measurement:

1. Pre-UV, water storage output
2. Post-UV, ozone post-destruction
3. Return flow, end of the water loop

The ISPE also recommends testing at the Point Of Use (POU) during normal line operation. Primary among the good reasons to monitor POU is to ensure the measurement of potential dead legs, which are a key breeding area for microbial growth. Once bio-film gets a foothold in a water system it is nearly impossible to remove. A portable ozone analyzer can be used for such operation on a rotating sample point basis.

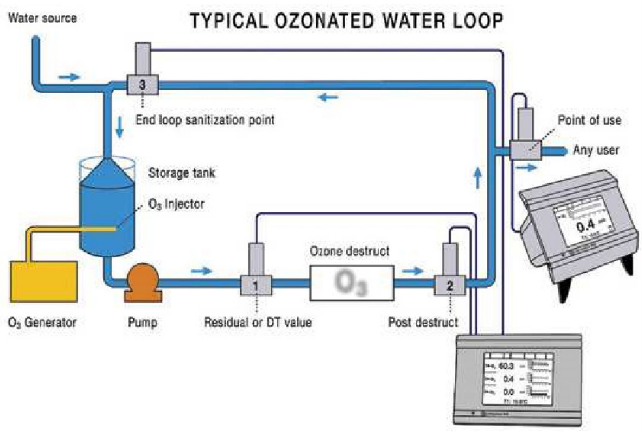

Fig. 2 Measurement locations for dissolved ozone

USP 29, 30 and 31 have requirements to show that WFI contain "no added substances" and "removal of chemical residues must be demonstrated". The meaning of this requirement is not only to measure accurately the ozone, but also to demonstrate that there is no ozone in water after the UV destruction. In other words a reliable low detection level of ozone in water is required for a measuring device.

How to Install an Ozone Sensor

Measuring directly in the process is a common trend seen in all industries since it removes the typical drawbacks of taking samples and carrying out laboratory analysis. Monitoring ozone in the process enables results to be obtained rapidly and with real time trending. In addition, with a suitable instrument, automatic control is also possible.

They are two different ways to install the ozone sensor in the process: in-line or off-line, each method has different advantages and limitations.(2)

1. Off-line Installation with Flow Cell

The water is extracted from the main line and goes into a flow chamber where the ozone sensor is inserted. The outlet goes to the drain, or ideally back into the water loop, before the main water tank. A flowmeter provides an alarm in case of low or no water flow.

The main benefit of this method is the smoothing effect it has on flow and pressure variations in the main line, reducing any noise on the measurement. This provides favorable monitoring conditions for low ppb trace level measurement, (especially after the ozone destruction) and longer service intervals. Another benefit of this setup is that it permits the sensor to be extracted (eg for service) without affecting the main water loop operation and with no hygienic risks affecting the line after the sensor re-introduced into the chamber. The sampling line should be as short as possible to avoid ozone decomposition in the sampling loop. This is especially important after a long plant shutdown when pipes need to be re-sanitized with ozone. If the sampling line is too long then it will take longer for the sensor to receive a sample that is representative of the process.

In order to reduce water loses the flow cell outlet should be connected to the suction side of the water pump in the water loop, (ideally before the main tank) instead of going to drain.

To watch:

- short sampling lines < 3m in stainless steel
- flowmeter with no/low flow alarm
- 1 flow regulator and 2 shutoff valves

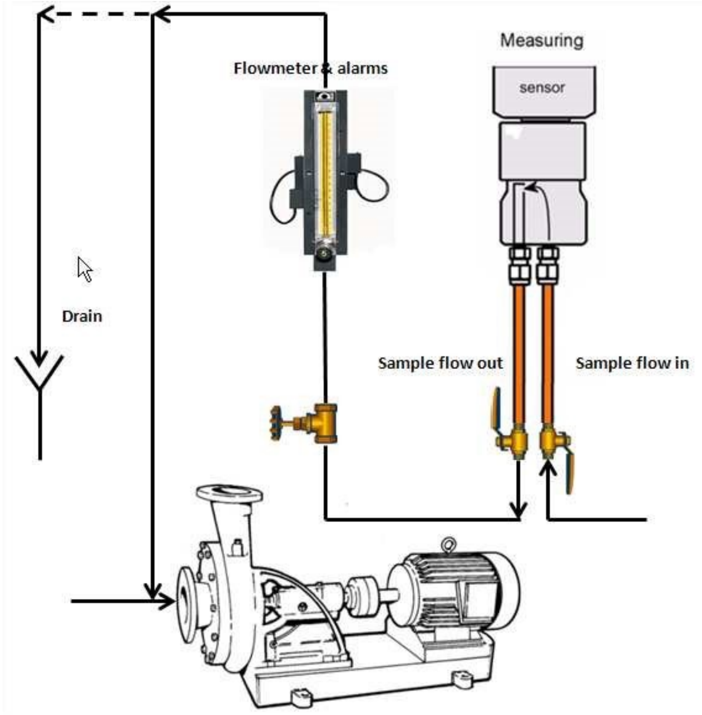

Fig. 3 Off-line sampling configuration with flow chamber

Fig. 4 ProAcc™ device and flange to install it

2. In-line Installation with the ProAcc Insertion Device

The second variant is the in-line installation using the Orbisphere ProAcc insertion device. A flange is first installed in the main pipe (see for instance the Varivent® Tuchenhagen AGG system), that receives the ProAcc™ device. Screwing the sensor into the device allows the sample to flow past the sensor. The ProAcc™ design allows the sensor to be completely removed without having to shut off the flow in the main water line. This provides flexibility for all services operations, but sensors can be re-introduced only during the sanitization phase. Nevertheless the direct in-situ measurement of the dissolved ozone provides quick and accurate results in any situation.

The table at the right provides a summary and comparison of the two installation methods

Criteria	In-line	Off-line
	ProAcc	Flow chamber
Ease of Installation	+	+ + +
Installation costs	+ +	+ +
Flow alarm requirement	+ + +	+
Access for service & contamination risk	+ +	+ + +
Service frequency	+ +	+ + +
Measurement stability at low conc.	+	+ + +
Grab sample for validation	-	+ + +
Response time to changes in the loop	+ + +	+
Compatibility w post O_3 injection	+ +	+ + +
Compatibility w post O_3 destruction	-	+ + +
Compatibility end water loop	+ + +	+ + +

Fig. 5 Comparison table in-line/off-line sensor installation

Calibration of Ozone EC Sensors

In brief, a calibration is a two step process: first a verification between a measuring device and a standard with greater accuracy, and secondly, an instrument adjustment if needed. Almost a third of the ASTM D7177 document is dedicated to calibration procedures, showing the importance of this operation.

Why calibrate?

- To detect, eliminate by adjustment and report any variation in the instrument's performance
- To follow regulations (FDA, Pharmacopeias) and guidelines that require calibration
- By-products may build-up on the surface of the sensor anode which generates a negative drift requiring compensation
- Since real time microbiological analysis does not currently exist, the continuous measure of dissolved ozone can be linked to the disinfection power applied to the water loop. The accuracy of this measurement improves confidence in the sanitization process.
- Reduces the risk of contamination

What is required for a reliable calibration process?

- Traceability, certified by National Standards
- Accuracy of the standard should be better than the measuring device (at least 2 times better)
- Shortest metrological traceability chain to
- National or Primary Standards
- Ease of operation in the field and metrological robustness
- Because no bottled ozone standard exists (ozone half-life=50% decay in less than 20 min at 25°C), metrological operations like calibration and validation require a specific strategy by combining several references [3].

What are the calibration options?

ZERO CALIBRATION

For sensors having an intrinsic zero, this operation is then a verification, i.e. a comparison with a reference without adjustment. The sensor is removed from the line and placed in contact with the air, free of ozone gas. With a noise at 0.0003 mg/L, the lowest detection limit is better than 0.001 mg/L (1 ppb). This provides reliable information on the UV lamp efficiency at the post destruction step.

SPAN

Three methods of span calibration are available for EC sensor users: titration, colorimetric (with portable photometer) and air calibration.

TITRATION

For titration the International Ozone Association has recognized a colorimetric method using indigo trisulfonate (i.e., the indigo method) as the recommended standard for measuring dissolved ozone in water [4]. It is recommended to measure three grab samples successively.

The indigo method is relatively easy to perform but has some drawbacks:

- Requires a convenient laboratory , some chemical agents, and a titration burette
- Remains operator dependent, from sample manipulation up to color change detection in the field, especially for low concentrations
- Accuracy and limit of detection is ±0.010 mg/L (10ppb)
- Additionally, with titration methods, the user must account for variability caused by grab samples variations (temperature, ozone half-life, sampling, etc) [5].
- The ozone concentration should be at concentrations higher than 0.100mg/L (100ppb) as the uncertainty of the titration can lead to important errors. For instance at a low concentration of 0.050 mg/L, ±0.010 mg/L gives an accuracy of ±20%.

Fig. 6 Hach DR300 Pocket Colorimeter

Several commercially available colorimetric kit with a portable photometer have taken the laboratory-based indigo method and adapted it so that it can be used in a process environment [6].

The ampoule containing the sample and the indigo reactive is inserted into a spectrophotometer (see Fig. 5) to quantify the color change. The test accuracy is specified at ±0.010 mg/L (10 ppb), excluding variations generated by the grab sampling. The same precautions taken with the indigo titration method should be observed here. Sometimes such kits have become the de facto standard for use with dissolved ozone analyzers in the industry. However, because of their poor accuracy at low ozone levels, it is best to use them for verification only (see further in the document) The use of a visible spectrophotometer is a better alternative than titration but the drawbacks of grab sample management remain.

AIR CALIBRATION

John Hale, who invented air calibration, discovered that oxygen could be measured with the same sensor used for ozone if the potential on the electrodes was changed [7]. The membrane-covered electrochemical sensor takes advantage of the similar physical properties of ozone and oxygen (e.g., molecular size and composition). Establishing the proper oxygen - ozone permeability ratio, using a known oxygen concentration, enables a linear ozone-calibration curve to be created with ±5% of reading accuracy in the 0–50 °C range. Thus, air calibration is a more accurate standard than the titration methods.

An advantage of using air calibration is that no reagents are needed, and the sample variation of grab samples is eliminated. Although air calibration is quick, readjustment of the sensor from measuring oxygen in air back to dissolved ozone may take several hours at low ozone concentrations. This drawback is now removed with the use of a specific portable ozone generator, which exposes the sensor to a high ozone concentration for few minutes. The readjustment time can then be reduced to less than 30 minutes. After more than 20 years and thousands of sensors, the robustness of the air calibration method has been proved in the field.

Fig. 7 Ampoule with dried reagent for quick check of DO_3 (Hach AccuVac)

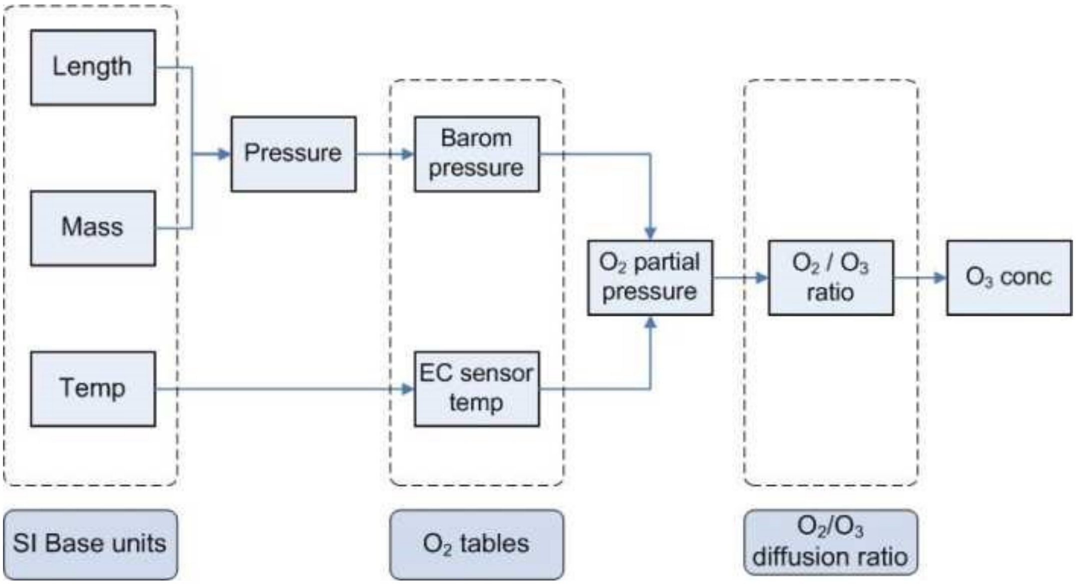

Fig. 8 Metrological traceability chain of the EC sensor

How is the Sensor Verified?

This operation is not mandatory but verification improves confidence (and reduces risk) by comparing measurement variation during normal water process operation. This may be the case when operators using air calibration feel frustrated since the sensor is not calibrated in the same medium that it operates in, even if this calibration is traceable (see next section).

Comparison of three measurements with a colorimetric method should be within a range of 0.015 mg/L. As mentioned before, colorimetric verification is more convenient than traditional titration. Whether using the actual titration apparatus or the commercial kit, the analyzer value then is compared with value obtained from the indigo method.

If it is within the combined margin of error (typically ±0.02 mg/L), then it is considered verified. Again care should be taken during the whole procedure concerning sample management and metrological traceability of the spectrophotometer established.

Verification is also done as part of the final sensor manufacturing control, after an air calibration, where an ozone gas phase validation is carried out with a certified UV spectrophotometer.

Verification is also done as part of the final sensor manufacturing control, after an air calibration, where an ozone gas phase validation is carried out with a certified UV spectrophotometer.

Metrological Traceability

Traceability is an important parameter when performing calibration. It allows an accurate calibration to be carried out and to ensure the best performance of the measuring device.

The measurement of oxygen, strictly speaking of the oxygen partial pressure in the air, is well understood (7) and by using a certified barometer and thermometer, the transmitter automatically determines the oxygen content in the air. As shown on Fig.6 all parameters are traceable to SI base units. The two branches of the chain (pressure and temperature) are also short enough to avoid high uncertainty addition during calibration.

Conclusion

In-line or off-line, each method has strengths and weaknesses. It is important to understand these and relate them to the specific site in order to make the most appropriate choice.

Calibrations with the colorimetric method and in the air, with a suitable instrument, are both described in the ASTM D7677-11. The benefit of this standard is to provide a clear procedure with all aspects of the continuous measurement of dissolved ozone in low conductivity water.

Although spectrophotometers and air calibration both show unbroken chains of metrological traceability, the air calibration of the sensor span has an advantage. This is confirmed by the operation of thousands of devices installed in the field and because of the robustness of the method combined with a high accuracy. On the other side spectrophotometers are well suited to quick verification and also calibration, under special conditions.

The publication of this ASTM standard will have positive consequences through driving improvements in calibration and dissolved ozone measurement confidence, process efficiency and data comparison between different sites. This standard can be purchased on-line at the ASTM website: (http://www.astm.org/Standards/D7677.htm).

Basic Terms Used in Metrology

Accuracy is a qualitative expression of the closeness of a measurement's result to the true value.

Precision is a measure of repeatability. A high precision indicates the ability to repeat measurements within narrow limits.

Detection Limit is, also called LOD (limit of detection), is the lowest quantity of a substance that can be distinguished from the absence of that substance (a blank value) within a stated confidence limit, generally 99%. The 100-99=1% alpha error is the probability of false positive. The LOD is defined as 3 * the standard deviation of the blank or the noise.

Robustness is the measure of its capacity to remain unaffected by small but deliberate variations in procedural parameters.

Uncertainty is a quantitative term that represents a range of values wherein the true value may lie and how confident the cal lab is that it is so. Uncertainty and confidence is determined using statistical tools. Although it is common to refer to instrument specifications as "Accuracy Specs", for the most part instrumentation specifications are specified terms of uncertainty rather than accuracy.

Metrological Traceability is the property of a measurement result whereby the result can be related to a reference through a documented unbroken chain of calibrations, each contributing to the measurement uncertainty.

Verification is a provision of objective evidence that a given item fulfils specified requirements.

References:

1. Standard Test Method for the Continuous Measurement of Dissolved Ozone in Low Conductivity water,. s.l. : ASTM D7677-11, Feb 2011.

2. T. Blonshine, Dissolved Ozone in Pharmaceutical Water Systems: How and Where to Measure Dissolved Ozone, Pharmaceutical Technology April 2006 http://www.pharmtech.com/pharmtech/Article/Dissolv ed-Ozone-in-Pharmaceutical-Water-SystemsHo/ArticleStandard/Article/detail/316163,

3. IUPAC, Metrology traceability of measurement results in chemistry. Concepts and implementation (IUPAC technical report), 15 June 2011

4. International Ozone Association (IOA), Standardization Committee Report: Colorimetric Method for Determination of Traces of Ozone in Water (IOA, Scottsdale, AZ, 1989).

5. W.J. Masschelein et al., "Colorimetric Method for Manual Determination of Ozone Concentrations in Water," Ozone Science & Engineering, Special Issue on Quality Assurance in Ozone Practice (1998), pp. 443– 445.

6. AccuVac Ozone Analysis Kit (Hach Company, Loveland, CO).

7. J.M. Hale et al., "Ozone Detection," Orbisphere Technical Note, No. 19 (2003).

Hach Author:
Georges Schmidt
Hach Lange Sàrl
Geneva, Switzerland