Evaluation of low detection limits of a range of low-cost oxygen meters for anoxic treatments

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Introduction

A comparative investigation was conducted to assess the lower detection limits of a selection of oxygen meters and analysers commonly used for the anoxic treatment of cultural heritage materials. The aim was to establish the accuracy of low cost (<$600) meters at oxygen levels typically applied during anoxic treatments.[1] Because most low-cost oxygen meters are designed as human health and safety devices, they are intended to accurately measure oxygen near or just below the natural abundance of 20.9% rather than near zero or less than 0.3%, where anoxic treatments commonly take place. The <0.3% threshold has been deemed a necessary maximum oxygen level to ensure effective eradication of all physiological states of insect life.[1]

Methods

The investigation used a Systech Illinois EC911 oxygen analyser (~$5500), which is specified as being capable of detecting trace amounts of oxygen as low as 0.001%, or 1ppm. The Systech Illinois EC911's calibration was checked against NIST certified tanks of oxygen calibration gas in nitrogen immediately prior to the evaluation of a range of oxygen meters (see Tables 1 and 2). The Systech analyser was factory calibrated in 2016 with the installation of a new electrochemical sensor using 0.01% (100 ppm) oxygen calibration gas in nitrogen.

Table 1. Calibration gasses used to calibrate Systech analyser prior to evaluating a range of oxygen meters.

Manufacturer and Product Code	Gases and Quantities Present	Calibration Certificate	Flow Rate Valve on Tank
GASCO 58L-161-0.2	0.2%(2000ppm) O_2, balance N_2	NIST	0.5 Liters Per Minute
E-Gas Depot 27-0100-FX120	0.1% (1000 ppm) O_2, balance N_2	NIST	0.5 Liters Per Minute
GASCO 103L-159-100	0.1% (1000 ppm) O_2, balance N_2	NIST	0.2 Liters Per Minute

Table 2. Oxygen levels detected by the Systech analyser (columns on right) versus each calibration gas listed in Table 1. The two oxygen level readings displayed in grey and blue in the columns on the right reflect calibration assessments occurring prior to two tests on different days.

Oxygen content in calibration gas		**Oxygen level detected by Systech analyser**	
percent by volume	parts per million	percent by volume	parts per million
0.01%	100 ppm	0.0298%	298 ppm
		0.0290%	290 ppm
0.10%	1000 ppm	0.1030%	1030 ppm
		0.0936%	936 ppm
0.20%	2000 ppm	0.2310%	2310 ppm
		0.2090%	2090 ppm

The difference between the NIST calibrated gases and the Systech values ranged from 30 ppm with the 0.1% oxygen calibrant to 310 ppm with the 0.2% calibrant. Keeping these differences in mind, the Systech analyser was used as a reference tool when exposing a range of oxygen meters to oxygen levels below 0.50%.

The oxygen meters employed in this investigation are listed in Table 3 below. Note that the alarm speaker and vibration module were removed physically removed from the Dräger meter to maximize battery life during treatments.

Table 3. Oxygen meters evaluated for their ability to accurately detect low oxygen levels.

Sensor	Purchase date	Calibration notes
BW Honeywell Gas Alert Max XT II Multi-Gas Oxygen Monitor (marked 'A' for testing purposes)	10/2019	Factory calibrated before 10/2019
BW Honeywell Gas Alert Max XT II Single-Gas Oxygen Monitor (marked 'B' for testing purposes)	12/2019	Factory calibrated before 12/2019
Dräger PAC 5500 Single-Gas O2 monitor (physically modified)[i]	2015	Sensor replaced and calibrated to 17% O_2 ~10/2019
BW Technologies Gas Alert Extreme Single Gas 02 Detector (marked 'A' for testing purposes)	More than 2 years old	Unknown; >2 years old
BW Technologies Gas Alert Extreme Single Gas 02 Detector (marked 'B for testing purposes)	10/2019	Factory calibrated before 10/2019
Sperian Biosystems Multipro by Honeywell with Multipro Remote Sampling Pump	06/2012	Calibrated to 20.9% and 0.0% O_2 04/2019
AnoxiBug by Hanwell Oxygen Sensor (marked 'P' for testing purposes)	Unknown	A2 sensor Sensor replaced 01/2020
AnoxiBug by Hanwell Oxygen Sensor (marked 'R' for testing purposes)	09/2018	A1 sensor Calibrated before 09/2018

[i] The Dräger PAC 5500 was physically opened, and both the speaker and vibration modules de-soldered from the board and removed. Without this modification, the battery life would not be sufficient for continuous in bag monitoring of treatments.

Product numbers of oxygen readers tested
Dräger PAC 5500 Single-Gas O2 monitor (VV-86515-07)
Anoxibug by Hanwell Oxygen Sensor (02-RX-P4-TX-434.075)
BW Honeywell Gas Alert Max XT II Single-Gas Oxygen Monitor (XT-X000-Y-NA)
BW Technologies Gas Alert Extreme Single Gas 02 Detector (GAXT-X-DL-2)
Sperian Biosystems Multipro by Honeywell with Multipro Remote Sampling Pump (54-48-314N)

The oxygen meters listed in table 3 were placed inside an ~18"x18" transparent Escal™ Neo Gas Barrier Film (ceramic oxide coated gas barrier film) bag, heat sealed on all sides, with two small holes at opposite corners. To match the ambient relative humidity in which the sensors had been stored, a ~50% RH humidified argon gas stream was fed into one hole, while the probe connected to the Systech analyser was fed into the other. Note that the AnoxiBugs had been stored at 0% RH according to the manufacturer's instructions prior to testing. The sensor ports were co-located as close to the center of the bag as possible. As the oxygen content inside the bag decreased, being replaced with argon, the oxygen levels displayed on the readers were recorded. Once the oxygen level of the Systech analyser reached the desired level (~5.0%, ~1.3%, ~1.2%, 0.415%, 0.2-0.25%, 0.17%, 0.139%, 0.096%, and 0.038-0.040%) the argon flow was

manually adjusted to maintain that level on the Systech analyser for 2-3 minutes to allow the Systech and the oxygen meters under test time to equilibrate. The readings on each oxygen meter were recorded after holding at a particular oxygen level for 2-3 minutes.

All but the AnoxiBug meters had digital displays, which reported oxygen content in percentages in increments of 0.1%. The AnoxiBug instruments had dual-colored LED bulbs that were advertised as illuminating in red when in 'high oxygen' environments and green in 'low oxygen' environments. For these, the color of the light was recorded at each oxygen level.

In addition to static readings, transition points between one reading and the next lowest reading for each meter in increments of 0.1% were also recorded using the oxygen level determined by the Systech analyser. For the AnoxiBug meters, only the transition between the flashing red LED and flashing green LED was recorded. The results of the tests are displayed in Table 4, with the data from the Systech analyser highlighted in grey in the top row. As several of the meters were borrowed from other institutions, data collection was determined by which oxygen meters were available, accounting for the empty cells.

Results

Table 4. Oxygen levels in % by volume detected by Systech instrument, highlighted in grey, were used as reference to compare the detection capabilities and transition points for several low-cost oxygen meters. Red infill indicates a low limit of detection that is too high, and green infill indicates a low limit of detection that is acceptable for use in anoxic treatments.

Oxygen Detector	Pump	Oxygen Level								
Systech Illinois EC911	active pump	(~5.0%)*	(~1.3%)*	(~1.2%)*	0.415% (4150 ppm)	0.2-0.25% (2000-2500 ppm)	0.170% (1700 ppm)	0.139% (1390 ppm)	0.096% (960 ppm)	0.038-0.040% (380-400 ppm)
Gas Alert Max XT II (A)	active pump	~5.0%	1.3%	1.2%	0.5%			0.2-0.1% transition	0.1-0.0% transition	0.0%
Gas Alert Max XT II (A) repeat	active pump					0.3%	0.2-0.1% transition		0.1-0.0% transition	0.0%
Gas Alert Max XT II (B)	active pump	~5.0%	1.3%	1.2%	0.5%	0.4-0.3% transition		0.3%		0.2-0.1% transition
Dräger PAC 5500	no pump					0.3%	0.2-0.1% transition		0.10%	0.1-0.0% transition
Gas Alert Extreme (A)	no pump		0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Gas Alert Extreme (B)	no pump		0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Sperian Biosystems Multipro	active pump				0.1-0.0% transition	0.0%	0.0%	0.0%	0.0%	0.0%
Anoxibug (R)	no pump	red	red	red to green transition	green	green		green	green	green
Anoxibug (P)	no pump	Red to green transition	green	Green	green	green		green	green	green

*To minimize operation of the Systech system at high oxygen levels, the Gas Alert Max XT II was used as the reference for these measurements

The Dräger PAC 5500 and Gas Alert Max XT II meters performed better than other meters at low oxygen levels. The Dräger displayed oxygen levels within 0.05% of those detected by the Systech analyser at ~0.3% oxygen, at its transition between 0.2-0.1% oxygen, and at ~0.1% oxygen. The greatest variation of oxygen level difference between the Dräger and Systech analyser occurred at the lowest oxygen level recorded, when the Sytech analyser read ~0.040% and the Dräger transitioned from 0.1-0.0% oxygen. The Gas Alert Max XT II instruments also tracked the oxygen levels well in comparison to the Systech analyser overall.

Their readings were identical at oxygen levels above 0.25% oxygen. The two Gas Alert Max XT II (A and B) meters deviated significantly from one another at oxygen levels below 0.139%, where meter A transitioned to zero at 0.96% oxygen and meter B never transitioned to zero.

While the differences at low oxygen levels between the Gas Alert Max XT II meters is significant, because both meters read 0.1% when the oxygen levels were 0.1%, these particular meters can be used for anoxic treatments. Similarly, because only one Dräger PAC 5500 meter was available for testing, it is unclear whether differences, meter to meter, exist in that product line.

Table 4 shows that both the old (A) and newly purchased (B) Gas Alert O_2 Extreme meters were unable to accurately measure oxygen levels below 1.3% oxygen; both of which displayed a 0.0% at this and all lower oxygen levels. Similarly, the AnoxiBug meters failed to display accurate readings at levels sufficient for effective anoxic treatment. The 'R' AnoxiBug meter transitioned to a green, or 'low oxygen' reading at ~1.2% oxygen as detected by the Systech analyser, and the 'P' Anoxibug meter transitioned to 'low oxygen' indication when the Systech analyser detected ~5.0% oxygen by volume.

Conclusions

This research was aimed at establishing whether low-cost (<$600) oxygen meters used for anoxic treatments of cultural heritage objects are capable of accurately measuring oxygen contents at low oxygen levels (0.010-0.30% O_2). Inexpensive oxygen meters are typically designed to monitor ambient oxygen levels for human health and safety applications, and therefore, are quite accurate at oxygen levels near 20.9% and are less accurate at lower oxygen levels. Although considerably more expensive at ~$5500, oxygen analysers, such as the Systech Illinois EC911 used in this testing, are purpose built to accurately reading low parts per million levels of oxygen.

The data collected herein suggests that inexpensive oxygen meters can provide usable low oxygen readings. While not precise, these meters, if calibrated with a NIST certified gas, can establish that oxygen concentrations are at or below the calibrant level as long as the display reads a number greater than 0.0%. The best low cost meters tested for low oxygen measurements include the BW Honeywell Gas Alert Max XT II and Dräger PAC 5500, which function well at oxygen levels around 0.1% by volume, while the Gas Alert Extreme, Sperian, and Anoxibug meters failed to display accurate readings at similar oxygen levels. Variation was observed in the accuracy capabilities of all meters tested, with different levels of sensitivity observed even within meters of the same make and model that were purchased within a few months of each other.

Given the limited number of meters tested in this study, and the significant variation in capabilities, it is highly recommended that meters be regularly referenced to at least one NIST certified tank of calibrant gas that is near the level desired for treatment.[2] The meter must read and maintain a number greater than zero to ensure it is capable of registering at the desired oxygen level. Ideally, more than one calibrant gas oxygen concentration is utilized to verify a meter's capabilities.

Disclaimer

Due to the very small sample sizes, the conclusions in this report as they relate to any one make and model of oxygen meter should not be applied as either condemnation or support for the use of that meter. Users are

encouraged to consult manufacturers for tools that will best serve their purposes and establish your particular meter's ability to accurately assess oxygen levels using NIST certified calibrant gases.

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[1] Maekawa, S. & Elert K. 2003. *The Use of Oxygen-Free Environments in the Control of Museum Insect Pests*. Los Angeles: Getty Publications.

[2] While in this study 0.2 and 0.5 lpm fixed flow regulators were used, for meters with integrated pumps, demand flow regulators are recommended with maximum flow rates that exceed the capability of the meter's pump. Unless a meter will be placed within the confines of the low oxygen atmosphere for the duration of an anoxic treatment, a meter with an active pump is recommended to allow the withdrawal of gas from an anoxic treatment container to allow accurate verification of the oxygen level within the treatment container.