CCR's, Oxygen (O2) Cell Linearity, Limiting, & You

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As long time instructor, both active and inactive over time, I do not want this to be a reflection on training that anyone may, or may not, have been taught in their classes. I simply consider Oxygen (O2) cell linearity to be central to our safety and ability to manage a CCR competently. There are many CCR divers that may not bother with linearity and consider it is a waste of time. Others may view it as driving without a seat belt- while many may get away with it over and over again, when an incident occurs, not having a seat belt often contributes to an ending with horrible results.

What is oxygen cell linearity? Is it real? Is it something that we really need to worry about? Why? We hope to address these questions moving forward.

Oxygen (O2) cell linearity is a mathematical method to predict the health and performance of O2 cells. As CCR divers we often calibrate our cells with air (21% PPO2) and/or one atmosphere of oxygen which we consider 1.0 PO2 (100% oxygen). If an O2 cell registers 10mv in air, what would we expect from a perfectly linear cell at 1.0 PO2? We are dealing with a partial pressure of O2 so we must divide the 10mv with that percentage (21%) to anticipate what the pure O2 voltage will be. Simply 10mv/0.21=47.6mv. This tells us that, with a linear cell, we can anticipate that cell will read 47.6mv after completing an O2 flush.

As depth increases, so too does the pressure. Raising the pressure of O2, as we go deeper, opens the opportunity to go beyond the 1.0 PO2 check we performed at the surface. Most CCR divers run a set point of 1.0 or higher which means that the surface O2 flush has not provided an accurate picture of linearity to the industry accepted limit, which is 1.6 PO2. If a cell is limited (discussed later in this article) we could realistically have a PO2 of 2.0 and not know it. This is why a 20'/6m O2 flush is critical for both checking linearity and possible limiting. Before we move on to the 20'/6m check we need to know what the millivolts are with an O2 flush at the surface and determine how close to linear our cells actually are. The 20'/6m check should be performed on every single dive.

We have to be able to anticipate what a Cell should be able to provide, and then compare that to the reality of what the cell actually provides and note the differences. To do this we have to test our cells. After checking our cells in air and doing the math to know what linear should be, we now flush our loop with pure O2 to observe how close to, or far away from, linearity we actually are. That difference, something we refer to as linear drift, is what is most important to us, otherwise we are just flying blind on our CCR's, IMHO.

Now we take that 10.0mv cell into pure O2 at the surface (1.0 PO2) and (for demonstration purpose, however very possible) we get 43mv. The question is are we OK with this? If we simply calibrate and move on, we have no idea if the cell is acceptable. Let's be clear, calibrating does not ensure cells are working properly or make any adjustment to your cells. All you are doing with calibration is setting your controller to what your cell output is. Most controllers don't care if your cell is within acceptable limits or not. If you don't know where you are comfortable with a cell that is at 10mv in air and 43mv in O2, this is what this article is about.

So we have linear at 47.6mv and actual at 43mv. To find our percentage to linearity we simply divide the lower number by the larger number. 43/47.6=90% which means that our cell is 90% linear or 10% away from linear. The question, which you are betting your life on, is whether you are comfortable with using a cell that has 10% linear drift at 1.0 PO2. Keep in mind that we consider 1.6 our physical limit, what PPO2 do you normally dive? If you are 10% off at 1.0 and diving 1.4 as a set point you could easily be at or above 1.6 simply due to lack of linearity. We have not yet performed an O2 check at 20 foot/6 meters. What mv number would you expect to see on that 20 foot 6 meter check? If you are not sure this is important.

We know that if we are linear we would expect to see 76.2mv with pure O2 at 20'/6m however we also know that we are 10% off of linear. What we would expect to see if our cell is holding its linear drift is 68.8mv. Simply 76.2X0.9=68.8mv. Now if we do our 20 foot/6 meter O2 check and we get 65mv, are you good with using this cell on the dive? We use the same math to determine how much linear drift we now have at our 20'/6m check. 76.2/65=85% linear or we can say that we now have 15% linear drift from air. Is 15% linear drift acceptable? If a set point of 1.4 is being run with a 15% linear drift the diver will easily be above 1.6 during the working portion of the dive. This is without considering any other errors which could make the difference, between shown and actual PO2, even greater.

There is an argument that we have 3 cells and our controllers have voting logic. The problem though is that if we aren't checking linearity for our cells, how do we know that they are operating within acceptable limits? Voting logic simply shows, or votes out, a cell that has reached enough deviation from the other two cells. It does not determine which cells are correct. Friends, that were highly experience CCR divers and explorers, have lost their life because of following voting logic that had only one good cell which was was voted out. Most controllers only accept what we input. Those controllers that have their limitations for linearity built in use their own pre-programmed parameters, are those parameters acceptable for the dive you have planned? Do you know what the programmed linear deviation is, if you're controller even has a limitation?

Another common way of avoiding linearity checks is to simply toss a cell once it goes below 10mv. Cells are rated at 12mv (the majority of CCR cells, the math is the same for any O2 cell) with many of them coming out of the bag a bit above that. The deviation between 12mv and 10mv is 16.6%, are you comfortable with a 16.6% linear deviation. The math is simple 10/12=83.3% linear or 16.6% linear deviation. I have had cells as low as 8mv that have been perfectly linear and ran well for over a year. Why throw a cell away that is performing well within expected parameters? I have had people tell me that it "won't calibrate". Again when you calibrate you are simply telling the controller of the actual output of your cells. There are some controllers that won’t allow you to calibrate when there is too much deviation between cells, however they don’t check the linearity and health of each individual cell, so they aren’t helping to increase safety. They are simply forcing us to throw a reliable cell in the garbage.