A guide to Rebreather Set-point selection.

There used to be a time when there was no safety margin in any activity that the human being wanted to participate in. In a merciless prehistoric world, on a daily basis, the cavemen were hunting with stones and sticks, a large variety of predators the size of a truck, expecting to feed a hungry family.

Then Winchester gave the men the ability to kill wild animals while staying at a comfortable distance, without risking their life. Safety margin was born.

As recreational divers, we were taught to plan for realistic safety margins. Remember: Rule number one states that you should always start your final ascent with at least 50 bar/500 psi in your cylinder.
As a technical diver, you suddenly discovered that this safety margin wasn't enough when doing deeper dives with required decompression, or even worse, when diving in an overhead environment.

As rebreather divers, what kind of safety margin do we have?

Rebreather diving is not an exact science

1. PO2 reading can be inaccurate – even properly calibrated, oxygen sensors fail to show the same oxygen content in a loop. Their age, their chemical properties or simply the humidity in the loop all helps to avoid any kind of accuracy on the pO2 readings. Even the famous voting logic is a pathetic attempt to be a little closer to the exact pO2. And it becomes even worse when the calibration is improperly done…

2. O2 exposure limits are variable – When dealing with Oxygen exposure, it looks like everything is quite vague. The NOAA tables are based on empirical data. The calculations for repetitive oxygen exposures are more than unclear. Even the maximum pO2 could change from one day to the other one in the same person, as shown by Kenneth Donald during WWII.

3. Decompression calculations are approximate – In this area, the idea seems to be: "nobody knows". Everything is as confusing as Sherlock Holmes and his riddles. A lot of theories, algorithms, procedures and decompression curves are discussed and experimented every day by "Guinea pigs" technical divers.

4. Off-gassing could be impaired by a lot of DCS contributing factors – Age, fitness level, illness, PFO, body fat or even history of DCS, pick your choice. How could a complex phenomenon like inert gas off-gassing could realistically be mimicked by a mathematical equation? Add one or all of these contributing factors and you get something that looks as complex.

So if everything is so complex, how could we possibly understand what could happen to a rebreather diver on a physiological standpoint? If the pO2 in the loop is too high, how could we predict the threshold of the oxygen toxicity? If the pO2 is too low, is the decompression requirement planned will be in accordance with what the diver actually experiment?

What could lead to oxygen toxicity?

When it comes to rebreather diving, Hyperoxia is the bad guy. The upper limit of PO2 is clearly more dangerous than the lower. People can fear hypoxia and its lethal consequences, but it takes time to happen. High pO2 is sometimes just a matter of seconds.

The three main reasons for having a high level of oxygen in a rebreather loop are:

1. A problem with the electronics.
One of the causes is a *bad calibration*. It could be due to:
- A different level of humidity in the gas one uses for calibration, compared to what could be found in the loop during the dive.
- An incorrect ambient pressure when the sensors are calibrated in altitude, if the user indicates that it's done at sea level.
- An incorrect fiO2 in the oxygen used for calibration.
- An incorrect fiO2 in the air used for calibration, in case of a 2 point calibration.
- Any excessive pressure in the loop during the calibration. This pressure is generally caused by an obstruction on the flow rate (closed mouthpiece, stuck OPV, backpressure caused by an analyzer connected to the loop, etc)

But it could also be a *false PO2 reading* on the handsets. Most of the time, the problem seems to be an old cell or a current limited cell.

2. An user error:
- A fast descent will create an O2 spike
- A wrong setpoint will unnecessarily increase the O2 content in the loop – for instance selecting a high setpoint before descending
- An excessive manual O2 injection
- A wrong diluent selection, if the oxygen content in the diluent is too high for the depth planned
- An oxygen exposure exceeding the physiological limits

3. A problem with the gas supply:
- Using a wrong gas, if the O2 or diluent tanks haven't been analysed
- An O2 leak in the loop, either because of the solenoid stuck in an open position or because of a leaking schraeder valve

One of these factors is Setpoint selection (user error). In technical diving, dive planning is all about safety margins. So why don't we plan for some safety factors when we choose the Setpoint for deep CCR dives? Why rebreather divers mostly use high pO2 setpoints?

A poll on the Rebreather World forum showed that more than half of the CCR divers use pO2 setpoints higher than 1.2 bar throughout the dive, sometimes increasing this setpoint during the last part of the ascent.

The reason for such a practice could be found in the fear of hypoxia (solenoid stuck close or rapid ascent). It could also be seen as a way to decrease their decompression obligation. But the main reason is maybe the fact that 1.3 is the default setpoint on the Inspiration/Evolution, the most popular units on the market. For some divers, it's simply easier to use the default setpoint than modifying it every time the electronics is turned on.

On the other hand, a lower PO2 setpoint gives a lot of benefits:
1. Oxygen Exposure – a low PO2 in the loop during the working part of the dive helps to keep the oxygen exposure quite reasonable. Therefore the body's natural ability to deal with high pO2 levels will be saved for the later part of the dive and the decompression stops.

2. Time to deal with emergency – a lower setpoint gives more time to deal with an increasing level of oxygen in the loop. Whatever the cause of the problem (mechanical, electronics, user error), a rebreather will always need more time to go above 1.6 bar, if the starting point is 1.0 instead of 1.3. It provides the CCR diver with a kind of buffer against major oxygen spikes.

3. Better PO2 reading - The sensors give a more accurate reading when dealing with low oxygen content. The user may not be aware that one of his/her O2 cell is current limited and has some difficulties to reach a high pO2. During the calibration process, all cells are supposed to reach 1.0 but nothing (except an O2 flush at depth) proves that the cell can read a higher value.

Okay for the benefits of a lower setpoint, but what about decompression?

- With an air diluent:

If your pO2 is 1.3 at 40m, your fraction of N2 actually in the loop should be around 73%. If the setpoint is 1.0, this fiN2 becomes 80%.

For a 60 minute dive, the decompression requirement is (according to V-Planner):
Bottom STP / Deco STP --> Ascent time
1,3 / 1,3 --> 48 min
1,0 / 1,0 --> 86 min
1,0 / 1,3 --> 60 min

- With a trimix diluent (Heliair 10/52):

If your pO2 is 1.3 at 80m, your fraction of inert gases actually in the loop should be around 86%. If the setpoint is 1.0, this fiN2 becomes 89%.

For a 30 minute dive, the decompression requirement is:

Bottom STP / Deco STP --> Ascent time
1,3 / 1,3 --> 141 min
1,0 / 1,0 --> 218 min
1,0 / 1,3 --> 157 min

With the proper setpoint selection (low setpoint at depth and higher in the shallows) it's only a 16 minute longer ascent for an almost 3 hour long dive. So we speak about a 10% increase in the decompression time.
And deeper or for longer bottom times, this increase is even smaller.

A reasonable safety margin?

When it comes to oxygen exposure, a rebreather diver should be well aware of the physiological limits he/she will be exposed to. Safety margin is everywhere in technical diving, as it's everywhere in the daily life.

What kind of safety margins should we use for deep or extremely long CCR dives?

1. For Gas management, we should use the rule of 1/3rds. At the end of the dive, a CCR diver should still have at least 1/3 of the oxygen cylinder left.

2. For decompression, all seasoned technical CCR divers increase the conservatism level and try to modify the off-gassing curve with gradient factors or deeper stops.

3. When it comes to hypercapnia, we make sure that we stay well within the recommended duration of the scrubber.

4. For Narcosis management, we should always make sure that the END at the maximum depth will always be lower than 30 or 40 m (100 – 130 ft) depending on the environment (cave, wreck, current, etc) and the mission.

5. For the Oxygen exposure, a competent CCR diver should always stay within reasonable limits and should select a setpoint lower than 1.3 for the bottom part of the dive, maybe increasing this setpoint during the decompression phase.

Remember: if the cavemen were able to survive in a very hostile environment, it's because they learnt to implement some safety margins in their daily activities by designing appropriate tools and clever hunting strategies.

A rebreather diver should do the same in order to survive deep and/or extremely long dives. Safety margin is a must when it comes to pO2 setpoint selection.

References

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