UNDERSTANDING AND SAFE USE OF PPO2 SET-POINTS FOR CCR

by Stéphane Havard, August 2002

The ideas through this page source in the teaching I received mixed with my understanding, my experience, and those of other divers. Some are certainly false and they should not be used without the theoretical and practical teaching from a CCR instructor.

Choice of the initial set-point (surface)

This parameter is often neglected but it is of prime importance in order to keep a reasonable PpO2 value at the end of the descent. The count of the PpO2 at the end of the descent is often ignored or wrongly understood and this could be a cause of severe accidents.

Table I illustrates the changes in PpO2 while going down with air as diluent and with an initial set-point of 0.7 bar (default value on Inspiration). The important role of this initial value of the set-point and the one of the oxygen fraction injected with the diluent are underlined with yellow colour.

Depth	Oxygen added / Pressure added		Amb P	PpO2 counter	FiO2
surface	0,7 b	1 b	1 b	0,7 b	70 %
10 m	0,21 b	+ 1 b	2 b	+ 0,21 = 0,91 b	46 %
20 m	0,21 b	+ 1 b	3 b	+ 0,21 = 1,12 b	37 %
30 m	0,21 b	+ 1 b	4 b	+ 0,21 = 1,33 b	33 %
40 m	0,21 b	+ 1 b	5 b	+ 0,21 = **1,54 b**	31 %
50 m	0,21 b	+ 1 b	6 b	+ 0,21 = **1,75 b**	29 %
60 m	0,21 b	+ 1 b	7 b	+ 0,21 = **1,96 b**	28 %

Table I : PpO2 during a descent on diluent air

It is shown that below 30 meters, using these "standard" conditions, the risk of reaching a dangerously elevated PpO2 value is real. Note that the nitrox mix in the loop is getting poorer but that PpO2 is increasing. If the initial set-point is lowered to 0.5 bar, then the 40 meters is safer since PpO2 at the end of the descent becomes 1.34 bar. The amount of oxygen metabolized by the diver does not reduce much the global amount of oxygen in the loop. But a diluent flush is efficient and allows a safe deeper descent.

Effect of a diluent flush

A diluent flush pushes out of the loop the mix that you are breathing and replaces it with diluent. The flush must be technically perfect. The PpO2 counter is then reset to the value of the PpO2 from the diluent breathed at the depth of the flush, as if the diver was breathing the diluent on open circuit. The loop is cleared of the relative excess of PpO2 that was present in the surface nitrox. The flush needs to be performed soon enough during the descent to prevent reaching a too high PpO2 once on the bottom or even earlier. The loop should be flushed again on the bottom.

Depth	Oxygen added / Pressure added		Amb P	PpO2 counter	FiO2
surface	0,7 b	1 b	1 b	0,7 b	70 %
10 m	0,21 b	+ 1 b	2 b	+ 0,21 = 0,91 b	46 %
20 m	0,21 b	+ 1 b	3 b	+ 0,21 = 1,12 b	37 %
30 m	0,21 b	+ 1 b	4 b	+ 0,21 = 1,33 b	33 %
Diluent flush at 30 meters					
30 m	4 b x 0,21 = 0,84 b	4 b	4 b	reset at 0,84 b	**21 % (air)**
40 m	0,21 b	+ 1 b	5 b	+ 0,21 = **1,05 b**	**21 %**
50 m	0,21 b	+ 1 b	6 b	+ 0,21 = **1,26 b**	**21 %**

Table II : PpO2 changes during a descent on diluent air with diluent flush

It is shown on **Table II** that after the diluent flush, the PpO2 during the descent follows the value it would have had on open circuit. The flush clears the relative excess of oxygen in the initial loop (the rich nitrox). It provides also two other major benefits. The flush clears the CO2 accumulated in the loop during the preparation before the jump in the water and during descent. On trimix dives, the flush evacuates also the neutral gas from the surface diluent (air most often) and replaces them with gas from the bottom diluent (richer in helium) to prevent narcosis.

The diluent flush preventively performed here provides the same "curative" benefits in potentially dangerous situations:
- low PpO2;
- high PpCO2;
- high PpN2 and narcosis.

This underlines the vital importance of an appropriate bottom diluent.

Descent

That type of descent with successive levels may lead to a threatening PpO2. Imagine that you are diving at 20 meters on the top of a wreck and that you stabilized at that depth after switching to the high-set point of 1.3 bar. Ten minutes later you eventually decide to go down to the sand at 40 meters. You may never make it to the bottom ...

With an air diluent you will add 2 bar (the 20 meters of depth difference) x 21 % (air) i.e. 0.42 bar of oxygen and then reach on the bottom the PpO2 of 1.3 + 0.42 i.e. 1.72 bar. Of course the FiO2 decreases by dilution of the nitrox mix with air, but PpO2 still increases while descending! This is another good reason to keep a high set-point value around 1.0 bar. This value keeps you a sufficient buffer in both directions, towards hypoxia (0.16 bar) and towards hyperoxia (1.6 bar).

Depth	Oxygen added / Pressure added		Amb P	PpO2 counter	FiO2
surface	0,7 b		1 b	0,7 b	70 %
10 m	0,21 b	+ 1 b	2 b	+ 0,21 = 0,91 b	46 %
20 m	0,21 b	+ 1 b	3 b	+ 0,21 = 1,12 b	37 %
Level at 20 meters with switch to high set-point					
20 m	high set - point 1,3 b	3 b	3 b	reset at 1,3 b	43 %
30 m	0,21 b	+ 1 b	4 b	+ 0,21 = 1,51 b	38 %
40 m	0,21 b	+ 1 b	5 b	+ 0,21 = **1,72 b**	34 %
50 m	0,21 b	+ 1 b	6 b	+ 0,21 = **1,93 b**	32 %

Table III : PpO2 during a descent with air diluent and a level at 20 meters

In such situation, the best procedure is to switch back to the low set-point and perform a diluent flush before going down to much deeper levels. If you do not switch back to the low set-point, oxygen may be injected by the solenoid after the diluent flush if it lowers the Pp02 below the high set-point.

Two dangerous attitudes during descent

Manual oxygen injection

We noticed that PpO2 sufficiently increases during descent just with diluent admission in the loop, to keep a breathable volume of mix. The PpO2 value reached at the end of the descent nears reasonable values of bottom PpO2 (1.0 to 1.3 bar). It is then absolutely not useful to inject oxygen in the loop during the descent; this procedure is even extremely dangerous and some CCR divers close their oxygen tank during descent and open it once on the bottom. This seems to me unnecessary and may lead to other substantial troubles.

Early switch on high set-point

Since diluent admission in the loop during descent leads to a satisfactory bottom PpO2, it is not necessary and even dangerous to switch to high set-point during descent. This procedure may have the same result as manual injection of oxygen and may dangerously increase PpO2. The diver is then in the situation of a "stair descent" with an intermediate PpO2 that is higher than in the case of a straight descent without switch. The switch on the high set-point (bottom set-point) should be performed only once on the bottom, in calm, without rush, and should not lead to an automatic (solenoid) injection of oxygen since the PpO2 resulting at the end of the descent nears the bottom PpO2.

If the PpO2 is too high when the diver reaches the bottom, it may arise from several causes:
- a surface PpO2 that is too high;
- a diluent that is too rich in oxygen (wrong mix and/or mix not checked);
- a manual injection of oxygen during descent;
- an early switch to the high set-point;
- a stair type descent;
- and a solenoid malfunction.

Choice of the bottom set-point

Oxygen factor: Nitrox effect

Chronic or acute hyperoxia gives a limit to the depth of use of the diluent. In leisure diving activities, it is commonly accepted that PpO2 should not exceed 1.45 bar for bottom mix and 1.6 bar for deco mix at rest. These values should be drastically lowered if dives are long or stressful (current, cold water or work). With a closed-circuit rebreather, safety margins should be extended since automatic or manual injection of oxygen or diluent may instantly but substantially increase the PpO2. The theoretical benefit of a "high" PpO2 on the bottom is to shorten the deco time since it reduces the proportion of neutral gas in the diluent (FiN2 and/or FiHe).

This benefit should be useful mostly for deep dives (below 70 meters), but at such depth the increase of PpO2 from 1.0 to 1.3 bar will only provide a little increase of the FiO2 (a few percent, see **Table IV**) and the small decrease of neutral gas in the diluent will have little consequences on saturation and deco times. On the opposite, this increase from 1.0 to 1.3 bar and even higher, will dramatically and dangerously shrink the safety margin towards hyperoxia.

Matter of concern: Navy divers, who spend hours on CCR and have the best reason to shorten their deco, use a PpO2 value of 0.7 bar during their entire dive (see CCR dive tables in US Navy Diving Manual).

	Set - point				
Depth	**0,5**	**0,7**	**1**	**1,3**	**1,6**
0 m	50%	70%	100%	*130%*	*160%*
10 m	25%	35%	50%	65%	80%
20 m	17%	23%	33%	43%	53%
30 m	13%	18%	25%	33%	40%
40 m	10%	14%	20%	26%	32%
50 m	8%	12%	17%	22%	27%
60 m	7%	10%	14%	19%	23%
70 m	6%	9%	13%	16%	20%
80 m	6%	8%	11%	14%	18%
90 m	5%	7%	10%	13%	16%
100 m	5%	6%	9%	12%	15%
110 m	4%	6%	8%	11%	13%
120 m	4%	5%	8%	10%	12%
130 m	4%	5%	7%	9%	11%

Table IV : FiO2 versus set-point and depth

Diluent factor: the "normo-mix" depth

As long as the Pp02 in the loop is below the selected set-point, the solenoid injects oxygen (or the diver does it manually) to reach the set-point and breathe a nitrox mix. In this situation the equivalent air depth is shallower than the actual depth, as with nitrox on open circuit, but with a CCR the content in oxygen of the mix in the loop is constantly modified with depth changes to keep a constant PpO2. The nitrogen is involved through the equivalent air depth that corresponds to its breathed partial pressure.

Once the diver reaches and remains at the "normo-mix "depth, i.e. the depth where the PpO2 on the diluent mix equals the value of the selected set-point, the breathed mix is straight diluent, without oxygen added. The EAD equals the actual depth. **Table V** gives the "normo-mix" depth versus the set-point.

If the diver goes deeper, below the "normo-mix" depth, the PpO2 provided by the diluent will be higher than the one of the set-point. The Constance of the PpO2 will be roughly achieved by the oxygen consumption by the diver metabolism. The mix in the loop will then be poorer in oxygen and concomitantly will be richer in nitrogen. The mix in the loop becomes richer in nitrogen than the diluent mix: it is nitrogen enriched air and the EAD is deeper than the actual depth, with consequences on narcosis and decompression.

The problem stands differently with a trimix or heliox diluent. Below the "normo-mix" depth, the increase in neutral gas in the loop mix compared to the diluent mix remains exact, with consequences on saturation and decompression. But depending on trimix composition in helium and nitrogen, the EAD may still be shallower than the actual depth. With a heliox diluent, the EAD is of course always equal to zero.

Below the "normo-mix" depth, the PpO2 will be raised above the set-point during diluent admission in the loop and may reach a dangerous level. Consequently a diluent flush will be unable to reduce the PpO2 in the loop in case of threatening hyperoxia. This situation should hence be avoided.

Set-point	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**	**1.0**	**1.1**	**1.2**	**1.3**	**1.4**	**1.5**	**1.6**
"Normo-mix" depth	**14 m**	**18 m**	**23 m**	**28 m**	**33 m**	**37 m**	**42 m**	**47 m**	**52 m**	**56 m**	**61 m**	**66 m**

Table V (diluent is air)

Choice of deco set-point

The choice of the deco set-point is easier. In ideal conditions as planned during the program phase of the dive, deco time should be spent on the shot line, effortlessly. The diver may then increase more safely the PpO2 to enhance and shorten the decompression. The set-point could be increased to 1.3 bar in such conditions. Once at six meters, oxygen flush could be performed to stabilize the PpO2 around 1.5 bar. If the deco happens in stress conditions (current, effort), PpO2 should be kept at 1.3 or even 1.0 bar during the deco.

Lots of personal beliefs and pseudo-theoretical concerns separate rebreather divers who are adept of a diluent switch during deco from the ones sticking to the "one-gas-all-the-way" faith. I have done both. I usually use now a diluent change when it will shorten the deco of at least 15-20 minutes in cold water. I switch then from a 8/62 bottom diluent to an air or a nitrox 32 deco diluent at 40 meters.

Other matter of concern: some CCR divers keep a set-point value of 1.0 bar during the whole deco because it has been shown that higher PpO2 values may alternate ventilatory and circulatory functions and so reduce the quality of the decompression.

Conclusion:

I hope that this page contributed to a better understanding of the changes in PpO2 during the dynamic phases of the CCR dives. Let me know if you notice anything that is wrong. CCR diving needs a lot more thinking than open circuit diving, before and during the dive. A perfect understanding of the role of set-points and diluent mix admission in PpO2 changes is necessary to prevent dramatic mistakes and a good diluent is necessary to protect you from our three primary fears: hypoxia, hyperoxia and hypercapnia.