Counterdiffusion Diving

Using Benthic Mix Switching to Reduce Decompression Time

BMX -- More Bottom Time – Less Deco!

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A recent article in Advanced Diver Magazine (Wienke and O'Leary, 2007) laid out the dangers and benefits of isobaric counterdiffusion to the technical diver. This article will introduce you to "Benthic Mix Switching," switching mixes on the bottom, a technique that takes advantage of the "good" isobaric counterdiffusion. Read on to enter the weird world of *Counterdiffusion Diving*, where you can off-gas without decompressing, enjoy a nice legal buzz, and cut your total stop time by 40%.

Try this at home.

Fire up your favorite mixed-gas decompression program and give me your best shot for a 130' dive for 90 minutes. Most likely you'll want to use nitrox with oxygen deco, but you'll have to dial back on the O2 in the nitrox mix to stay within exposure limits.

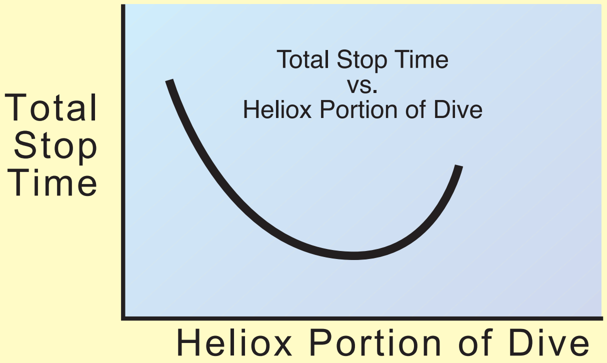
So what did you come up with for total stop time? ProPlanner, with 28% nitrox and deco on the bottom mix and oxygen, gave a total stop time of 85 minutes. But using an interesting new technique called Benthic Mix Switching, or BMX, you can cut that by 40% to about 50 minutes! For longer dives, you can save even more time.

Here's how.

Plug in the same dive, 130' for 90 minutes, only this time start the dive with 5 minutes of heliox. Use the same percent O2 as the nitrox and do the rest of the bottom time, 85 minutes, on the nitrox and finish up with oxygen decompression. What happens to the total stop time? It drops a little. Try it again with 10 minutes of heliox and 80 minutes of nitrox. Total stop time drops again. Do more trials adding five minutes of heliox while reducing the nitrox portion by five minutes to maintain a bottom time of 90 minutes.

What you'll find, as shown in Figure 1, is that as the heliox time at the beginning of the dive increases, the total stop time decreases, reaching some minimum value before it increases again. That minimum value marks the optimum time for the switch from heliox to nitrox during the bottom portion of the dive. That is Benthic Mix Switching.

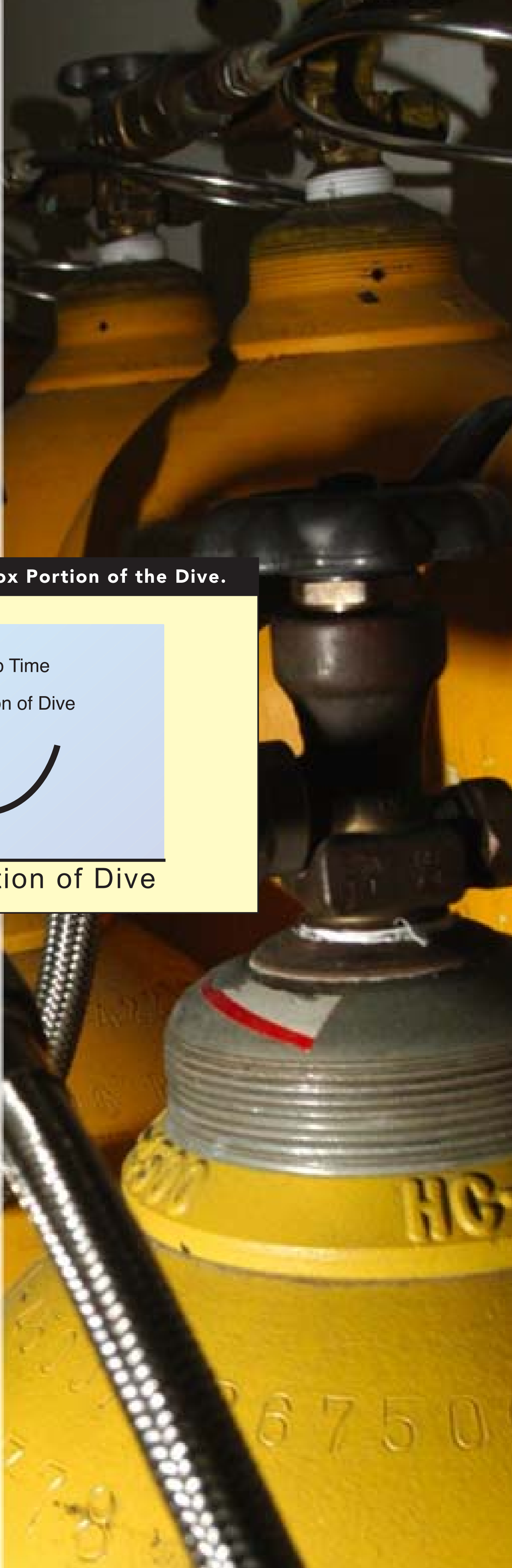
Figure 1. Total Stop Time vs. Heliox Portion of the Dive.



Why does that happen?

The answer lies in the physical differences between helium and nitrogen. Graham's Law states that the rate at which a gas will diffuse into or out of a liquid is inversely proportional to the square root of its molecular weight. Using Graham's Law, we find that helium will diffuse into and out of a liquid about 2.6 times faster than nitrogen.

This means that if a diver breathing heliox switches to nitrox on the bottom, without changing depths (a benthic or isobaric mix switch), the helium will begin diffusing out of his or her tissues faster than the nitrogen will be diffusing in ("Good" Isobaric Counterdiffusion illustration above). The situation where gasses are moving in opposite directions is called "counterdiffusion," and for the diver it can be good or bad. When a diver has more than one inert gas onboard, the decompression obligation depends on the sum of the inert gas tissue tensions. Following a benthic or isobaric mix switch from heliox to nitrox there is a decrease in the total inert gas tissue tension, and this causes a reduction in total stop time.

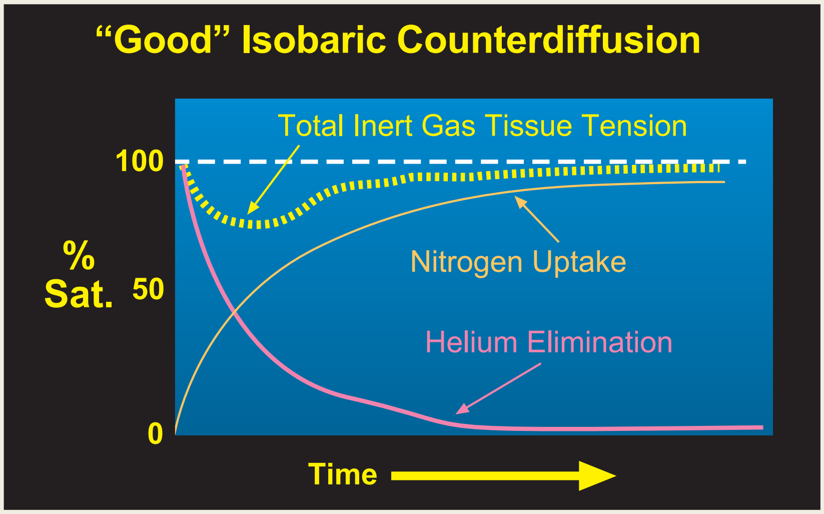


“Good” Isobaric Counterdiffusion

Researchers studying isobaric counterdiffusion used the terms “subsaturation” (Lambertsen, 1978), “desaturation” (Lambertsen and Idicula, 1975; Wienke, 2001), and “undersaturation” (D’Aoust, 1983) to describe the theoretical decrease in total inert gas tissue tensions following an isobaric mix switch from heliox to nitrox. Yount (1982) used hypothetical tissue halftimes to illustrate that mix switching could reduce decompression below that of either mix used alone. Animal experiments (D’Aoust, 1983) supported the theory that advantageous mix switches, such as helium-to-nitrogen, could produce a decompression advantage.

Figure 2 illustrates the case where tissues are at or near saturation with helium, and the diver’s breathing mix is switched to a nitrogen mix. The total inert gas tissue tension will temporarily drop (Keller and Bühlmann, 1965; Lambertsen and Idicula, 1975; Lambertsen, 1978; D’Aoust, 1983; Wienke, 2001) because the helium is diffusing out faster than the nitrogen is diffusing in. This creates a decompression advantage that may be optimized by carefully timing the mix switch (Keller, 1967). Using the trial-and-error method above, you were able to easily determine the optimal time for that switch. Open water demonstration dives in December 2003 (Taylor, 2005), showed that the theory worked in practice.

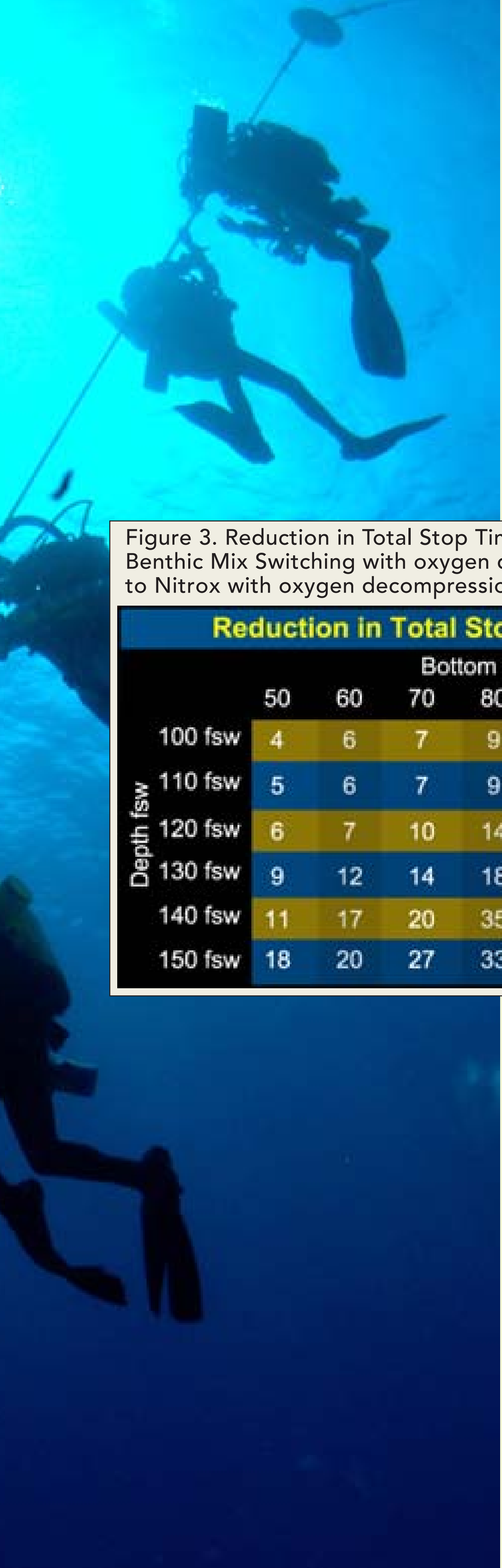
Figure 2. Showing the reduction of total inert gas tissue tension following a Benthic or Isobaric Mix Switch from heliox to nitrox.



Early pioneers

Experiments begun in 1959 by Hans Keller and Albert Bühlmann (Keller and Bühlmann, 1965; Keller, 1967 & 1968) first made use of the idea that different inert gases have different saturation speeds and that by switching mixes containing these inert gases, based on the rate at which these gases are taken up and eliminated by the body, a decompression advantage would result.

Beginning in 1962, chamber experiments sponsored by the U.S. Navy used multiple inert gases to optimize decompression from deep dives ranging from 130 fsw to 1,000 fsw. Of the many experimental dives in this series, one used an isobaric mix switch. That dive was performed in a chamber to a depth of 130 fsw for 120 minutes, used seven human subjects, switched from oxygen /helium (40/60) to oxygen / argon (40/60) after seventy minutes, and used oxygen for the final portion of the decompression.



In 1975, Bühlmann described the theoretical benefits of Isobaric Mix Switching in an identical dive profile that substituted nitrogen for argon in the second mix. These experimental and theoretical dive profiles demonstrated a major decompression advantage over conventional methods, but are impractical for open-water diving because they far exceed tech diving oxygen exposure limits.

Try this at sea.

Divers from the NOAA Undersea Research Center performed four 60-minute test dives using Benthic Mix Switching at the Speigel Grove off Key Largo in 130 fsw in December of 2003. They used side-mounted heliox (27/73) cylinders as they would a travel tank breathing it from the surface to the bottom until they reached the optimum switch time, in this case about twenty minutes. Three of the four divers experienced a rather pleasant, transient, enhanced narcotic effect — a nice legal buzz. The divers then swam along the bottom entirely around the wreck, collecting enough equipment to start a small dive shop, and ended the dive at one hour. Decompression was done using VR3s and matched the theoretical reduction in total stop times expected. Since that time, divers from NURC/UNCW have used the technique for servicing instrumented trawl-proof cages and moorings in 130 – 140 fsw off North Carolina with significant reductions in decompression time for square dives, and huge reductions on multilevel dives.

Figure 3. Reduction in Total Stop Time in Minutes Using Benthic Mix Switching with oxygen decompression compared to Nitrox with oxygen decompression.

Reduction in Total Stop Time Using BMX

Depth fsw	Bottom Time (minutes) 50	60	70	80	90	100	110	120
100 fsw	4	6	7	9	9	11	15	25
110 fsw	5	6	7	9	12	19	33	37
120 fsw	6	7	10	14	22	31	32	44
130 fsw	9	12	14	18	34	33	68	66
140 fsw	11	17	20	35	34	53	65	-
150 fsw	18	20	27	33	60	54	-	-

How much stop time does it save?

Benthic Mix Switching typically reduces total decompression time by 30%-40%. As Figure 3 shows, the greater the exposure, the greater the savings in time. Figure 4 compares the total stop times for 130 fsw dives for various bottom times using nitrox with oxygen decompression and Benthic Mix Switching using oxygen decompression.

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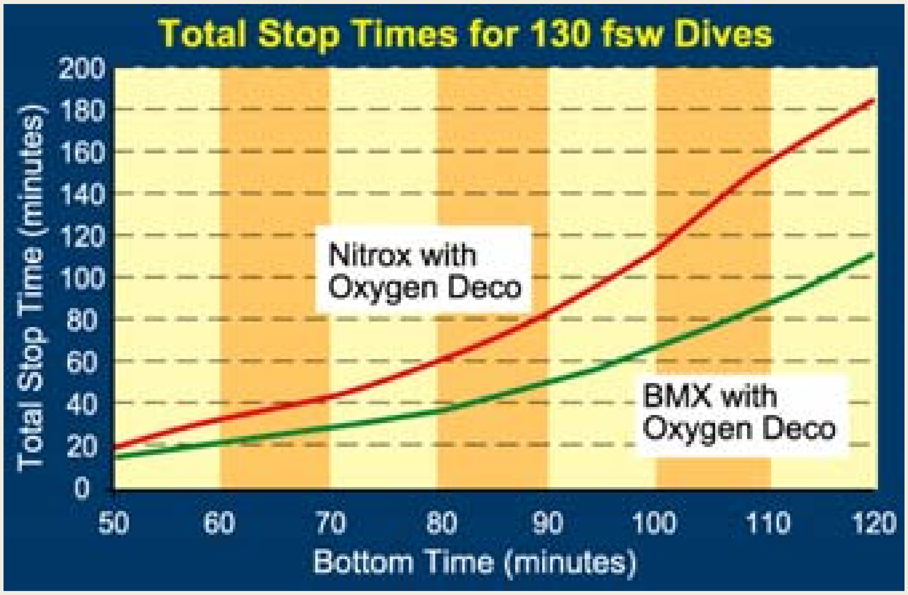
Any downside?

Benthic Mix Switching is only useful for long dives in the deep nitrox range. BMX requires technical diving equipment and techniques, rebreathers, or surface-supplied gear. The diver must be qualified on the mix and the equipment used. Helium is expensive, but then so are all the steps that bring one to this type of diving.

Some researchers suggest that divers may be susceptible to inner ear decompression sickness due to counterdiffusion when using switches from helium to nitrogen-rich mixes even without decompression (Doolette and Mitchell, 2003).

Figure 4. Comparison of Total Stop Times for a 130 fsw dive for various bottom times using Nitrox with oxygen deco and BMX with oxygen decompression.



On the plus side...

Benthic Mix Switching uses standard technical diving equipment and techniques. BMX calculations can be done using any mixed gas decompression program, and the dive can be controlled with any programmable mixed gas diving computer. The diver need not use the rule of thirds with the heliox since switching back to this mix would be a bad idea. We sent our spend heliox cylinders to the surface.

Benthic Mix Switching optimizes the bottom time/decompression time equation. You may use BMX to increase bottom time for a given total decompression time or reduce decompression for a given bottom time. BMX improves dive efficiency in two ways: first it reduces decompression time, and second, because deco time is shorter, it allows higher partial pressures of oxygen in the bottom mix.

Practical Matters

Oxygen toxicity is the biggest single factor in planning this type of dive. Some dives were only possible with this technique, because it reduced decompression enough to allow the dive to be within O2 limits. We used a 27/73 mix for our dives to simplify things. We ordered the heliox in K bottles from a commercial vendor and mixed the nitrox to match it. This mix, while not the optimal mix for all dives, was good over a range of depths and provided a safety margin with regard to oxygen toxicity during working dives.

Benthic Mix Switching is not a panacea. It is simply another tool in our bag of tricks that enables us to reduce decompression for long dives in the deep nitrox range. It worked well for servicing moorings where we knew the depth and needed more time. It should be really useful for divers using rebreathers and surface supplied gear where extended dives with open circuit gear are impractical.

In addition to the momentary buzz from the switch, it's a novel experience to see the total "Time-To-Surface" on my VR3 dive computer go down as I continue my dive, showing that I am off-gassing without decompressing!

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